PROCEEDINGS

OF

THE ROYAL SOCIETY.

April 12, 1888.

Professor G. G. STOKES, D.C.L., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The Bakerian Lecture was delivered as follows:—

THE BAKERIAN LECTURE.—"Suggestions on the Classification of the various Species of Heavenly Bodies." A Report to the Solar Physics Committee. Communicated at the request of the Committee. By J. NORMAN LOCKYER, F.R.S.

CONTENTS.

[Received March 21, 1888.]

PART I.—PROBABLE ORIGIN OF SOME OF THE GROUPS.

I. *Nebulæ.*

In a paper communicated to the Royal Society on November 15th, 1887, I showed that the nebulæ are composed of sparse meteorites, the collisions of which bring about a rise of temperature sufficient to render luminous one of their chief constituents—magnesium. This conclusion was arrived at from the facts that the chief nebula lines are coincident in position with the fluting and lines visible in the bunsen burner when magnesium is introduced, and that the fluting is

far brighter at that temperature than almost any other spectral line or fluting of any element whatever.

I suggested that the association or non-association of hydrogen lines with the lines due to the olivine constituents of the meteorites might be an indication of the greater or less sparseness of the swarm, the greatest sparseness being the condition defining fewest collisions, and therefore one least likely to show hydrogen. This suggestion was made partly because observations of comets and laboratory work have abundantly shown that great liability to collision in the one case, and increase of temperature in the other, are accompanied by the appearance of the carbon spectrum instead of the hydrogen spectrum.

The now demonstrated meteoric origin of these celestial bodies renders it needful to discuss the question in somewhat greater detail, with a view to classification; and to do this thoroughly it is requisite that we should study the rich store of facts which chiefly Sir William Herschel's labours have placed before us regarding the various forms of nebulæ, in order to ascertain what light, if any, the new view throws on their development.

To do this the treatment must be vastly different from that—the only one we can pursue—utilised in the case of the stars, the images of all, or nearly all, of which appear to us as points of light more or less minute; while, in the case of the nebulæ, forms of the most definite and, in many cases, of the most fantastic kind, have been long recognised as among their chief characteristics.

It will at once be evident that since the luminosity of the meteorites depends upon collisions, the light from them, and from the glow of the gases produced from them, can only come from those parts of a meteor-swarm in which collisions are going on. Visibility is not the only criterion of the existence of matter in space; dark bodies may exist in all parts of space, but visibility in any part of the heavens means, not only matter, but collisions, or the radiation of a mass of vapour produced at some time or other by collisions. The appearances which these bodies present to us may bear little relation to their actual form, but may represent merely surfaces, or loci of disturbance.

It seemed proper, then, that I should seek to determine whether the view I have put forward explains the phenomena as satisfactorily as they have been explained by old ones, and, whether, indeed, it can go further and make some points clear which before were dark.

To do this it is not necessary in the present paper to dwell at any great length either on those appearances which were termed *nebulosities* by Sir William Herschel or on irregular nebulæ generally; but it must be remarked that the very great extension of the former —which there is little reason to doubt will be vastly increased by

increase of optical power and improvement in observing conditions and stations—may be held to strengthen the view that space is really a meteoritic *plenum*, while the forms indicate motions and crossings and interpenetrations of streams or sheets, the brighter portions being due to a greater number of collisions per unit volume.

From this point of view it is also possible that many stars, instead of being true condensed swarms due to the nebulous development to which we have referred, are simply appearances produced by the intersection of streams of meteorites. They are, then, referable to an intensification of the conditions which gave rise to the brighter appearances recorded by Herschel here and there in his diffused nebulosities. The nebulous appendages sometimes seen in connexion with stars strengthen this view.

When we come to the more regular forms we find that they may be generalised into three groups, according as the formative action seems working towards a centre; round a centre in a plane or nearly so; or in one direction only. As a result we have globular, spheroidal, and cometic nebulæ. I propose to deal with each in turn.

Globular Nebulæ.

The remarkable appearance presented by the so-called planetary nebulæ requires that I should refer to them in some detail. Sir William Herschel does not describe them at any great length, but in his paper on "Nebulous Stars" he alludes to the planetary nebulosity which in many cases is accompanied by a star in the centre, and finally comes to the conclusion that "the nebulosity about the star is not of a starry nature" ('Phil. Trans.,' vol. 81, 1791, p. 73.)

Sir John Herschel, in his valuable memoir published in 'Phil. Trans.,' 1833, describes them as "hollow shells" (p. 500). It was so difficult to explain anything like their appearance by ordinary ideas of stellar condensation that Arago, as quoted by Nichol ('Architecture of the Heavens,' p. 86), abandoning altogether the idea that they represented clusters of stars or partook in any wise of a stellar constitution, imagined them as hollow spherical envelopes, in substance cloudy and opaque, or rather semi-transparent; a brilliant body invisible in the centre illuminating this spherical film, so that it was made visible by virtue of light coming through it and scattered by reflection from its atoms or molecules.

Lord Rosse ('Phil. Trans.,' vol. 140, 1850, p. 507) records that nearly all the planetary nebulæ which he had observed up to that time had been found to be perforated. In only one case was a perforation not detected, but in this ansæ were observed, introducing into the subject for the first time the idea of nebulous bodies resembling to a certain extent the planet Saturn. But Lord Rosse, although he thus disposed of the idea of Arago, still considered that the annular

nebulæ were really hollow shells, the perforation indicating an apparently transparent centre.

Huggins and Miller subsequently suggested that the phenomena represented by the planetary nebulæ might be explained without reference to the supposition of a shell (or a flat disk) if we consider them to be masses of glowing gas, the whole mass of the gas being incandescent, so that only a luminous surface would be visible ('Phil. Trans,' vol. 154, 1864, p. 442).

It will be seen that all these hypotheses are mutually destructive; but it is right that I should state, in referring to the last one, that the demonstration that these bodies are not masses of glowing gas merely has been rendered possible by observations of spectra which were not available to Dr. Huggins when his important discovery of the bright-line spectrum of nebulæ was given to the world.

It remains, then, to see whether the meteoritic hypothesis can explain these appearances when it is acknowledged that all the prior ones have broken down. If we for the sake of the greatest simplicity consider a swarm of meteorites at rest, and then assume that others from without approach it from all directions, their previous paths being deflected, the question arises whether there will not be at some distance from the centre of the swarm a region in which collisions will be most valid. If we can answer this question in the affirmative, it will follow that some of the meteorites arrested here will begin to move in almost circular orbits round the common centre of gravity.

The major axes of these orbits may be assumed to be not very diverse, and we may further assume that, to begin with, one set will preponderate over the rest. Their elliptic paths may throw the periastron passage to a considerable distance from the common centre of gravity; and if we assume that the meteorites with this common mean distance are moving in all planes, and that some are direct and some retrograde, there will be a shell in which more collisions will take place than elsewhere. *Now, this collision surface will be practically the only thing visible, and will present to us the exact and hitherto unexplained appearance of a planetary nebula—a body of the same intensity of luminosity at its edge and centre—thus putting on an almost phosphorescent appearance.*

If the collision region has any great thickness, the centre should appear dimmer than the portion nearer the edge.

Such a collision surface, as I use the term, is presented to us during a meteoric display by the upper part of our atmosphere.

I append a diagram, Fig. 1, which shows how, if we thus assume movement round a common centre of gravity in a mass of meteorites, one of the conditions of movement being that the periastron distance shall be somewhat considerable, the mechanism which produces the appearance of a planetary nebula is at once made appa-

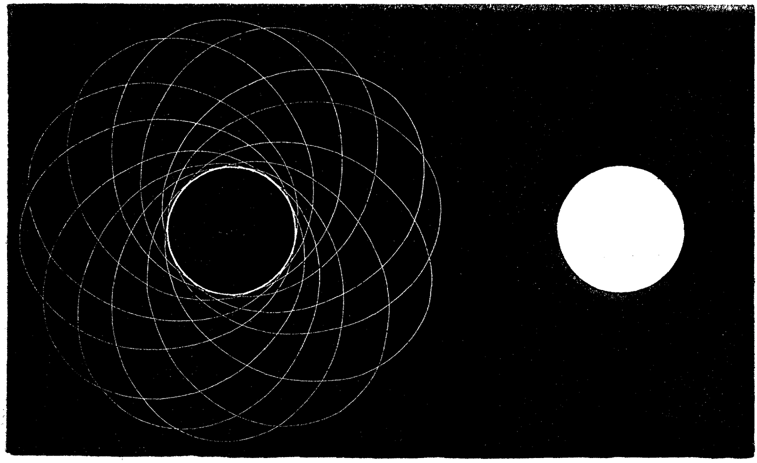

FIG. 1.—Suggested origin of the appearance presented by a planetary nebula. The luminosity is due to the collisions occurring along the sphere of intersection of the elliptic orbits of the meteorites. The left-hand diagram is a cross-section of the meteoric system, and the right-hand one shows the appearance of the collision-shell as seen from a point outside.

rent. The diagram shows the appearance on the supposition that the conditions of all the orbits with reference to the major axis shall be nearly identical, but the appearances would not be very greatly altered if we take the more probable case in which there will be plus and minus values.

Globular Nebulæ showing Condensation until finally a Nebulous Star is reached.

If we grant the initial condition of the formation of a collision-shell, we can not only explain the appearances put on by planetary nebulæ, but a continuation of the same line of thought readily explains those various other classes to which Herschel has referred, in which condensations are brought about, either by a gradual condensation towards the centre, or by what may be termed successive jumps These condensations doubtless are among the earliest stages of nebular development.

To explain these forms we have only to consider what will happen to the meteorites which undergo collision in the first shell. They will necessarily start in new orbits, and it is suggested that an interior collision-shell will in this way be formed.

In consequence of the collisions the orbits will have a tendency to get more and more elliptic, while the pericentric distance will at the same time be reduced; the swarm will, in consequence of this action,

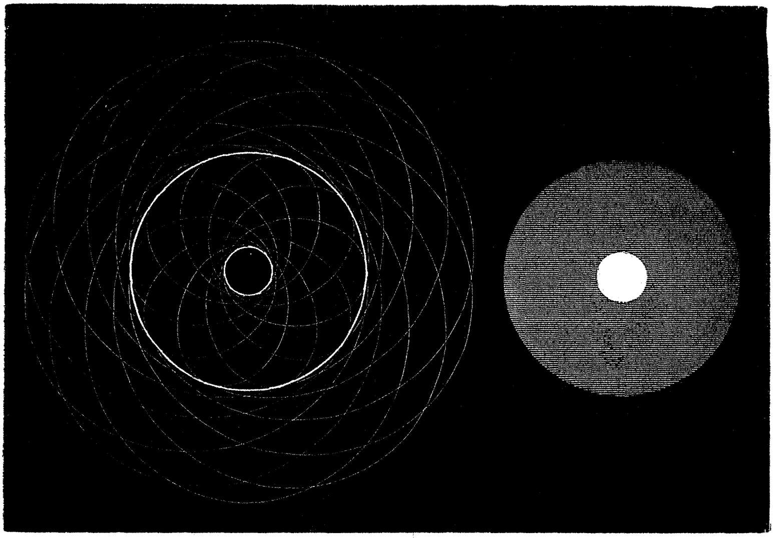

Fig. 2.—Suggestion as to the origin of a globular nebula with a brighter central portion. As in the former case, the luminosity of the fainter portion is due to the collisions which occur along the sphere of intersection represented by the larger circle. After collision the meteorites will travel in new orbits, and there will be an additional sphere of intersection, represented by the smaller circle. The left-hand diagram is a cross-section, and the right-hand one represents the appearance of the two collision-shells as seen from a point outside.

gradually brighten towards the centre through collisions being possible nearer the centre, and ultimately we shall have nebulæ with a distinct nucleus, the nucleus then representing the *locus* of most collisions. This brightness may be sudden in certain spherical surfaces, or quite gradual, according to the collision conditions in each swarm.

The final stage will be the formation of a nebulous star.

Effects of Subsequent Rotation.—Spheroidal Nebulæ.

In such meteor-swarms as those we have considered, it must be that rotation is, sooner or later, set up. Otherwise it would be impossible to account for the spheroidal nebulæ at all. I am aware that in Newton's opinion the cause of this rotation was not mechanical, but the moment we assume a meteoric origin of these globular clusters it is straining the facts to assume that the intake will be exactly the same at all points, and the moment the bombardment is more or less localised, rotation must follow sooner or later. Sir William Herschel, in his paper of 1811 (p. 319), says, "If we consider this matter in a general light, it appears that every figure which is not already globular must have eccentric nebulous matter, which, in its endeavour

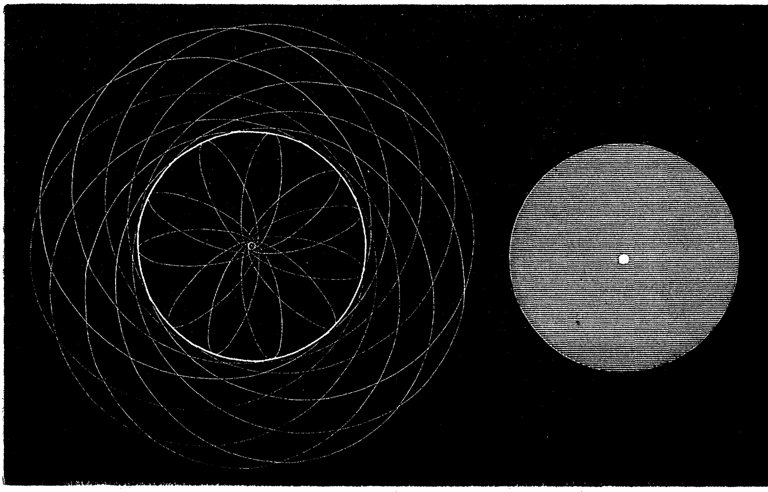

FIG. 3.—Suggestion as to the origin of a nebulous star. The orbits of the inner set of meteorites are very elliptic, so that the shell of intersection appears almost as a point. As in the previous cases, the left-hand diagram represents the meteoric systems in section, and the right-hand one the appearance from a point outside.

to come to the centre, will either dislodge some nebulosity which is already deposited, or slide upon it sideways, and in both cases produce a circular motion; so that, in fact, we can hardly suppose a possible production of a globular form without a subsequent revolution of nebulous matter, which in the end may settle in a regular rotation about some fixed axis."

Given, then, a globular swarm with a rotation around an axis, we have to discuss the phenomena produced by collisions under a new set of circumstances.

Here at once we have to account for the fact that the nearly spherical forms are very short-lived, for they are very rare; we seem to jump, as it were, from globes to very extended spheroids.

If it be conceded that from the above considerations we are justified in supposing that the elliptic and other spheroidal nebulæ really represent a higher stage of evolution than those presented to us by the globular form, it is clear that on the meteoritic hypothesis the greater part of the phenomena will represent to us what happens to such a system under the condition of a continuous bombardment of meteorites from without.

So soon as we have a minor axis, there will at first be most collisions caused by the movements of meteors, the paths of which are most nearly parallel to it; the result of this will be that the equatorial plane will be intensified, and then, later on, if we conceive the system

as a very extended spheroid, it is obvious that meteorites approaching it in directions parallel to its minor axis will have fewer chances of collisions than those which approach it, from whatever azimuth, in what we may term the equatorial plane. These evidently, at all events if they enter the system in any quantity, will do for the equatorial plane exactly what their fellows were supposed to do for the section in fig. 1, and we shall have on the general background of the symmetrically rotating nebula, which may almost be invisible in consequence of its constituent meteorites all travelling the same way and with nearly equal velocities, curves indicating the regions along which the entrance of the new swarm is interfering with the movements of the old one; if they enter in excess from any direction, we shall have broken rings or spirals.

This was suggested in my last paper. Various segments of rings will indicate the regions where most collisions are possible, and the absence of luminosity in the centre by no means demonstrates the absence of meteorites there.

Researches by Lord Rosse and others have given us forms of nebulæ which may be termed sigmoid and Saturnine, and these suggest that they and the elliptical nebulæ themselves are really produced by the rotation of what was at first a globular rotating swarm of meteorites, and that in these later revelations we pick up those forms which are produced by the continued flattening of the sphere into a spheroid under the meteoric conditions stated. It is worthy of remark that all the forms taken on by the so-called elliptic nebulæ described by the two Herschels, and by the spiral, sigmoid, and Saturnine forms which have been added to them by the labours of Lord Rosse and others, are recalled in the most striking manner by the ball of oil in Plateau's experiment, when rotations of different velocities are imparted to it.

The Saturnine form may, indeed, in some cases represent either the first or last stages in this period of the evolutionary process. I say *may* represent, in consequence of the extreme difficulty in making the observations so that in the early stages a spherical nebula, beginning to change into a spheroid, may have its real spheroidal figure cloaked by various conditions of illumination.

The true Saturnine form must, as in the case of Saturn itself, represent one of the latest forms in the meteor-swarm, because, if it be not continually fed from without, collisions must sooner or later bring all the members of the swarm to the centre of figure.

Cometic Nebulæ.

I do not know that any explanation has, so far, been suggested as to the origin of these curious forms, which were first figured by Sir William Herschel, and of which a number have recently been

observed in the southern hemisphere ('Observations of the Southern Nebulæ, made with the Great Melbourne Telescope,' Part I). It is clear that in them the conditions are widely different from those hitherto considered in this paper. I think that the meteoritic hypothesis satisfactorily explains them, on the supposition that we have either a very condensed swarm moving at a very high velocity through a sheet of meteorites at rest, or the swarm at rest surrounded by a sheet all moving in the same direction. It is a question of relative velocity.

If we consider the former case, it is clear that the collision region will be in the rear of the swarm, that the collisions will be due to the convergence of the members of the sheet due to the gravity of the swarm, and that the collision region will spread out like a fan behind the swarm.

The angle of the fan, and the distance to which the collisions are valid, will depend upon the velocity of the condensed swarm.

[Received March 26, 1888.]

II. *Stars with Bright Lines or Flutings.*

I pointed out in my last paper that those stars in the spectra of which bright lines had been observed were in all probability the first result of nebulous condensation, both their continuous spectrum and that of the surrounding vapour being produced by a slightly higher temperature than that observed in nebulæ in which similar though not identical phenomena are observed.

I have recently continued my inquiries on this point; and I may say that all I have recently learned has confirmed the conclusions I drew in my last paper, while many of the difficulties have disappeared. Before I refer to these inquiries, however, it is necessary to clear the ground by referring to the old view regarding the origin of bright lines in stellar spectra, and to the question of hydrogen.

Reference to the Old View by which it was supposed some of the Bright-line Phenomena might be accounted for.

In the views which, some years ago, were advanced by myself and others, to account for the bright lines seen in some of the "stars" to which reference has been made, the analogy on which they were based was founded on solar phenomena; the "stars" in question being supposed to be represented in structure by our central luminary. The main constituent of the solar atmosphere outside the photosphere is hydrogen, and it was precisely this substance which was chiefly revealed by these stellar observations and in the Novas, in which cases it was sometimes predominant. A tremendous development of

an atmosphere like that of the sun seemed to supply the explanation of the phenomena.

Acting on this view in 1878,* I attempted to catch these chromospheric lines in α Lyræ, abandoning the use of a cylindrical lens in front of the slit with this object in view.

Further, it was quite clear that if such gigantic supraphotospheric atmospheres existed, their bright lines might much modify their real absorption spectra; even "worlds without hydrogen" might be thus explained without supposing a *lusus naturæ*, and so I explained them.

That this view is untenable, as I now believe, and that it is unnecessary, will, I think, be seen from what follows. A long series of newly described phenomena, which are absolutely incomprehensible while it is applied to them, find, I think, a simple and sufficient explanation. I must hold that the view is untenable, because how a body constituted in any way like the sun could change its magnitude from the thirteenth to the sixth every year or so, or change its hydrogen lines from bright to dark once a week, passes comprehension; and the more closely a "star" resembles the sun the less likely are such changes to happen. Even the minor evolutionary changes are inexplicable on this hypothesis, chiefly because in a completely condensed mass the temperature must be very high and constant, while I have shown that the spectroscopic phenomena are those of a specially low temperature; and I may now add that many of the objects are extremely variable in the quantity and quality of the light they emit.

Another cause of the appearance of the hydrogen lines has been suggested by Mr. Johnstone Stoney ('Roy. Soc. Proc.,' vol. 17, p. 54). He considers it due to the clashing together of the atmospheres of two

* ". . . The sun which we see, the sun which sends us the majority of the light we receive, is but a small kernel in a gigantic nut, so that the diameter of the real sun may be, say, 2,000,000 miles. Suppose then that some stars have very large coronal atmospheres; if the area of the coronal atmosphere is small compared with the area of the section of the true disk of the sun, of course we shall get an ordinary spectrum of the star; that is to say, we shall get the indications of absorption which make us class the stars apart; we shall get a continuous spectrum barred by dark lines. But suppose that the area of the coronal atmosphere is something very considerable indeed, let us assume that it has an area, say fifty times greater than the section of the kernel of the star itself; now, although each unit of surface of that coronal atmosphere may be much less luminous than an equal unit of surface of the true star at the centre, yet, if the area be very large, the spectroscopic writing of that large area will become visible side by side with the dark lines due to the brilliant region in the centre where we can study absorption; other lines (bright ones) proceeding from the exterior portion of that star will be visible in the spectrum of the apparent *point* we call a star. Now it is difficult to say whether such a body as that is a star or a nebula. We may look upon it as a nebula in a certain stage of condensation; we may look upon it as a star at a certain stage of growth."—'Roy. Soc. Proc.,' vol. 27, 1876, p. 50.

stars, the outer constituent of the atmosphere—hydrogen—alone being raised by the friction to brilliant incandescence.

Another objection we can urge against the old view is that all bodies in the universe cannot be finished suns in the ordinary sense, and that it leaves out of account all possible processes of manufacture, not only of single stars, but of double and multiple systems, at all stages between nebula and sun; while the new one, by simply changing the unit from the star to each individual constituent, it is hardly too much to say, explains everything, though it is perfectly true that in some of the steps a considerable acquaintance with spectroscopic phenomena is necessary to realise the beauty and the stringency of the solutions.

The Question of Hydrogen in the Case of Bright-line Stars.

It may be convenient also that I should summarise the various conditions under which the lines of hydrogen are observed in the meteoritic swarms we are now considering.

In the "nebulæ" we begin with the widest interspaces. Future investigation may, as I have suggested, show that those in which the hydrogen lines are absent are the most widely spaced of all. Be this as it may, it is a matter of common knowledge that in the brighter nebulæ, such as that of Orion, to take an instance, we have hydrogen associated with the low-temperature radiation of olivine. That the hydrogen is electrically excited to produce this glow is proved by the fact that the temperature of the meteorites themselves must be very low; otherwise the magnesium would not show itself without the manganese and iron constituents, and the continuous spectrum would be much brighter and longer than it is.

In the former paper I showed that in my laboratory experiments, when the pressure was slightly increased in a tube containing gases obtained from meteorites, the carbon bands began to be visible. We should expect this to happen therefore in a meteor swarm at some point at which the mean interstitial space was smaller than that accompanied by the appearance of the hydrogen lines; and it would be natural that both should be seen together at an early stage and both feeble, by which I mean not strongly developed, as hydrogen is not strongly developed even in the nebula of Orion, none of the ultra-violet lines being visible in a photograph, while the magnesium line is.

The association of the low-temperature lines of hydrogen with the flutings of carbon is therefore to be expected, and I shall subsequently show that we have such an association in the so-called bright-line stars; and even at a further stage of development, in stars like α Orionis, the hydrogen is still associated with the carbon.

The Cometic Nature of Stars with Bright Lines in their Spectra.

Seeing that the hypothesis I am working on demands that the luminosity in stars and the bright lines in their spectra are produced by the collisions of meteorites, the spectra of those bodies must in part resemble those of comets, in which bodies by common consent the luminosity is now acknowledged to be produced by collisions of meteorites.

We must, however, consider the vast difference in the way in which the phenomena of distant and near meteoric groups are necessarily presented to us; and, further, we must bear in mind that in the case of comets, however it may arise, there is an action which drives the vapours produced by impacts outward from the swarm in a direction opposite to that of the sun.

It must be a very small comet which, when examined spectroscopically in the usual manner, does not in consequence of the size of the image on the slit enable us to differentiate between the spectra of the nucleus and envelopes. The spectrum of the latter is usually so obvious, and the importance of observing it so great, that the details of the continuous spectrum of the nucleus, however bright it may be, are almost overlooked.

A moment's consideration, however, will show that if the same comet were so far away that its whole image would be reduced to a point on the slit-plate of the instrument, the differentiation of the spectra would be lost; we should have an integrated spectrum in which the brightest edges of the carbon bands, or some of them, would or would not be seen superposed on a continuous spectrum.

The conditions of observation of comets and stars being so different, any comparison is really very difficult; but the best way of proceeding is to begin with the spectrum of comets, in which, in most cases, for the reason given, the phenomena are much more easily and accurately recorded.

But even in the nucleus of a comet as in a star it is much more easy to be certain of the existence of bright lines than to record their exact positions,* and as a matter of fact bright lines, including in all probability hydrogen, have been recorded, notably in Comet Wells and in the great comet of 1882.

The main conclusion to which my researches have led me is that the stars now under consideration are almost identical in constitution with comets between that condition in which, as in those of 1866 and 1867, they give us the absolute spectrum of a nebula and that put on by the great comet of 1882.

* "*Observations of Comet III*, 1881, *June* 25.—The spectrum of the nucleus is continuous; that of the coma shows the usual bands. With a narrow slit there are indications of many lines just beyond the verge of distinct visibility."—Copeland, 'Copernicus,' vol. 2, p. 226.

I am aware that this conclusion is a startling one, but a little consideration will show its high probability, and a summary of all the facts proves it, I think, beyond all question.

While we have bright lines in comets, it can be shown that some of them are the remnants of flutings. Thus in Comet III of 1881, as the carbon lines died away the chief manganese fluting at 558 became conspicuously visible; it had really been recorded before then. The individual observations are being mapped in order that the exact facts may be shown. It may probably be asked how it happened that the fluting of magnesium at 500 was not also visible. Its absence, however, can be accounted for: it was *masked* by the brightest carbon fluting at 517, whereas the carbon fluting which under other circumstances might mask the manganese fluting at 558 is always among the last to appear very bright and the first to disappear.

In the great comet of 1882, which was most carefully mapped by Copeland, very many lines were seen, and indeed many were recorded, and it looks as if a complete study of this map will put us in possession of many of the lines recorded by Sherman in the spectrum of γ Cassiopeiæ. We have then three marked species of non-revolving swarms going on all fours with three marked species of revolving ones, and in this we have an additional argument for the fact that the absence in the former of certain flutings which we should expect to find may be attributed to masking by the carbon flutings.

We have next, then, to show that there are carbon bands in the bright-line stars.

There is evidence of this. Among the bright lines recorded is the brightest carbon fluting at 517. This is associated with those lines of magnesium and manganese and iron visible at a low temperature which have been seen in comets.

But we have still more evidence of the existence of carbon. In a whole group of bright-line stars there is a bright band recorded at about 470, while, less refrangible than it, there appears a broad absorption band. I regard it as extremely probable that we have here the bright carbon band 467—474, and that the appearance of an absorption band is due to the fact that the continuous spectrum of the meteorites extends only a short distance into the blue.

If we consider such a body as Wells's comet, or the great comet of 1882, at so great a distance from us that only an integrated spectrum would reach us, in these cases the spectrum would appear to extend very far, and more or less continuously, into the blue; but this appearance would be brought about, not by the continuous spectra of the meteorites themselves, but by the addition of the hydrocarbon fluting at 431 to the other hot and cold carbon bands in that part of the spectrum.

There are other grounds which may be brought forward to suggest

that the difference between comets and the stars now under discussion is more instrumental than physical.

Supposing that the cometic nature of these bodies be conceded, laboratory work will eventually show us which flutings and lines will be added to the nebula spectrum upon each rise of temperature.

The difficulties of the stellar observations must always be borne in mind. It will also be abundantly clear that a bright fluting added to a continuous spectrum may produce the idea of a bright line at the sharpest edge to one observer, while to another the same edge will appear to be preceded by an absorption band.

III. *Stars with Bright Flutings accompanied by Dark Flutings.*

I also showed in the paper to which reference has been made that the so-called "stars" of Class III*a* of Vogel's classification are not masses of vapour like our sun, but really swarms of meteorites; the spectrum being a compound one, due to the radiation of vapour in the interspaces and the absorption of the light of the red- or white-hot meteorites by vapours volatilised out of them by the heat produced by collisions. The radiation is that of carbon vapour, and some of the absorption, I stated, was produced by the chief flutings of manganese.

These conclusions were arrived at by comparing the wave-lengths of the details of spectra recorded in my former paper with those of the bands given by Dunér in his admirable observations on these bodies.*

The discovery of the cometic nature of the bright-line stars greatly strengthens the view I then put forward, not only with regard to the presence of the bright flutings of carbon, but with regard to the actual chemical substances driven into vapour. From the planetary nebulæ there is an undoubted orderly sequence of phenomena through the bright-line stars to those now under consideration, if successive stages of condensation are conceded.

I shall return to these bodies at a later part of this memoir.

IV. *Stars in which Absorption Phenomena predominate.*

I do not suppose that there will be any difficulty in recognising, that if the nebulæ, stars with bright lines, and stars of the present Class III*a* are constituted as I state them, all the bodies more closely resembling the sun in structure, as well as those more cooled down, must find places on a temperature curve pretty much as I have placed

* "Les Étoiles à Spectres de la troisième classe."—'Kongl. Svenska Vetenskaps-Akademiens Handlingar,' Band 21, No. 2, 1885.

them; the origin of these groups being, first still further condensation, then the condition of maximum temperature, and finally the formation of a photosphere and crust.

We shall be in a better position to discuss these later stages when the classifications hitherto suggested have been considered.

Part II.—Classification into Groups.

I. Former Classifications of Stars.

In the various classifications of the celestial bodies which have been attempted from time to time, nebulæ and comets have been regarded as things apart from the stars; but from what I have stated in the first part of this paper, relating to the origin of the various groups of heavenly bodies, it is clear that it is not only unnecessary but unphilosophical to make such a distinction; and, indeed, if any such separation were needed, such a result would seem to indicate that the line of evolution is by no means so simple and clear as it really seems to be. But although it is no longer necessary to draw this distinction, it is important that I should state the various spectroscopic classifications which have been attempted in the case of the stars. With this information before us, we shall be better able to see the definite lines on which any new classification must be based to include all celestial forms.

Fraunhofer, Rutherfurd, and Secchi.

When we inquire into the various labours upon which our present knowledge of the spectra of the various orders of "stars" is based, the first we come across are those of Fraunhofer, who may be said to have founded this branch of scientific inquiry in the year 1814.

Fraunhofer not only instituted the method of work which now is found to be the most effective, but his observations at that time were so excellent that he had no difficulty in finding coincidences between lines in the spectrum of the sun and of Venus.

Fraunhofer's reference in his observations runs as follows:—

"I have also made several observations on some of the brightest fixed stars. As their light was much fainter than that of Venus, the brightness of their spectrum was consequently still less. I have nevertheless seen, without any illusion, in the spectrum of the light of Sirius, three large lines, which apparently have no resemblance with those of the sun's light. One of them is in the green, and two in the blue space. Lines are also seen in the spectrum of other fixed stars of the first magnitude; but these stars appear to be different from one another in relation to these lines. As the object-glass of the telescope of the theodolite has only thirteen lines of aperture, these

experiments may be repeated, with greater precision, by means of an object-glass of greater dimensions."*

He did not attempt to classify his observations on stellar spectra, but, as pointed out by Professor Dunér ("Sur les Étoiles à Spectres de la Troisième Classe," p. 3), those that he most particularly mentions are really remarkably diverse in their characteristics.

In these researches Fraunhofer was followed by Rutherfurd, who, in the year 1863, was the first to indicate that the various stellar spectra which he had then observed were susceptible of being arranged into different groups. His paper was published in 'Silliman's Journal' (vol. 35, p. 71), and, after giving an account of the observations actually made, continues as follows:—

"The star spectra present such varieties that it is difficult to point out any mode of classification. For the present, I divide them into three groups:—First, those having many lines and bands, and mostly resembling the sun, viz., Capella, β Geminorum, α Orionis, Aldebaran, γ Leonis, Arcturus, and β Pegasi. These are all reddish or golden stars. The second group, of which Sirius is the type, presents spectra wholly unlike that of the sun, and are white stars. The third group, comprising α Virginis, Rigel, &c., are also white stars, but show no lines; perhaps they contain no mineral substance, or are incandescent without flame."

Soon afterwards Secchi carried on the inquiry, and began in 1865 by dividing the objects he had then observed into two types. These two types were subsequently expanded in 1867 into three ('Catalogo delle Stelle di cui si è determinato lo Spettro Luminoso,' Secchi, Parigi, 1867): first, white stars, like α Lyræ; secondly, yellow stars, like Arcturus; and thirdly, deeply coloured stars, like α Herculis and α Orionis. The order of these types was not always as stated, but I have not been able to find the exact date at which the order was changed (Dunér, "Sur les Étoiles," p. 128). Secchi subsequently added a fourth type, in which the flutings were less numerous. There is little doubt that Secchi was led to these types not so much by any considerations relating to the chemical constitution of the atmospheres of these bodies, as in relation to their colours. His first classifications, in fact, simply separated the white stars from the coloured ones (see on this point 'Le Scopirte Spettroscopiche,' A. Secchi, Roma, 1865).

The fourth type included, therefore, stars of a deeper red colour than those of the third, and Secchi pointed out that this change of colour was accompanied by a remarkable change in the spectrum; in fact, of Secchi's four types thus established, the first and second had

* "On the Refractive and Dispersive Power of Different Species of Glass, with an Account of the Lines which cross the Spectrum."—Fraunhofer, translated in 'Edinburgh Philosophical Journal,' vol. 10, October to April, 1823–24, p. 39.

line spectra and the third and fourth had fluted ones. At that time the important distinction to be drawn between line- and fluted-spectra was not so well recognised as it is at present; and further the relation of spectra to temperature was not so fully considered. Secchi, as a result of laboratory work, however, at once showed an undoubted connexion between the absorption flutings in the stars of the fourth type and the bright ones seen in the spectrum or carbon under certain conditions; and although this conclusion has been denied, it has since been abundantly confirmed by Vogel and others (see Vogel, 'Publicationen, &c., Potsdam,' No. 14, 1884, p. 31).

Relation to Temperature.

At the time that Secchi was thus classifying the stars, the question was taken up also by Zöllner, who in 1865 first threw out the suggestion that the spectra might probably enable us to determine somewhat as to the relative ages of these bodies; and he suggested that the yellow and red light of certain stars were indications of a reduction of temperature (Zöllner, 'Photometrische Untersuchungen,' p. 243).

In 1868 this subject occupied the attention of Ångström with special reference to the contrasted spectra of lines and flutings. On this he wrote as follows, showing that temperature considerations might help us in the matter of variable stars ('Recherches sur le Spectre solaire,' Upsala, 1868):—

"D'après les observations faites par MM. Secchi et Huggins, les raies d'absorption dans les spectres stellaires sont de deux espèces: chez l'une, le spectre est rayé de lignes très-fines, comme le spectre solaire; chez l'autre, les raies constituent des groupes entiers à espaces égaux ou des bandes nuancées. Ces derniers groupes appartiennent vraisemblablement aux corps composés, et je mentionnerai, en particulier, que ceux trouvés dans le spectre de α Orionis ressemblent fort aux bandes lumineuses que donne le spectre de l'oxyde de manganèse. Supposé que ma théorie soit juste, l'apparition de ces bandes doit donc indiquer que la température de l'étoile est devenue assez basse pour que de telles combinaisons chimiques puissent se former et se conserver.

"Entre ces deux limites de température chez les étoiles, limites que l'on peut caractériser par la présence de l'une ou de l'autre espèce des raies d'absorption, on peut s'imaginer aussi un état intermédiaire, dans lequel les gaz composés peuvent se former ou se dissocier, suivant les variations de température auxquelles ils sont assujettis par l'action chimique même. Dans cette classe doivent probablement être comprises les étoiles dont l'intensité de lumière varie plus ou moins rapidement, et avec une périodicité plus ou moins constante."

In the year 1873, I referred to this subject in my Bakerian Lecture

('Phil. Trans.,' vol. 164, 1874, p. 492), in which I attempted to bring to bear some results obtained in solar inquiries upon the question of stellar temperatures.

I quote the following paragraphs :—

I. The absorption of some elementary and compound gases is limited to the most refrangible part of the spectrum when the gases are rare, and creeps gradually into the visible violet part, and finally to the red end of the spectrum, as the pressure is increased.

II. Both the general and selective absorption of the photospheric light are greater (and therefore the temperature of the photosphere of the sun is higher) than has been supposed.

III. The lines of compounds of a metal and iodine, bromine, &c., are observed generally in the red end of the spectrum, and this holds good for absorption in the case of aqueous vapour.

Such spectra, like those of the metalloids, are separated spectroscopically from those of the metallic elements by their columnar or banded structure.

IV. There are, in all probability, no compounds ordinarily present in the sun's reversing layer.

V. When a metallic compound vapour, such as is referred to in III, is dissociated by the spark, the band spectrum dies out, and the elemental lines come in, according to the degree of temperature employed.

Again, although our knowledge of the spectra of stars is lamentably incomplete, I gather the following facts from the work already accomplished with marvellous skill and industry by Secchi, of Rome.

VI. The sun, so far as the spectrum goes, may be regarded as a representative of class (β) intermediate between stars (α) with much simpler spectra of the same kind, and stars (γ) with much more complex spectra of a different kind.

VII. Sirius, as a type of α, is (1) the brightest (and therefore hottest ?) star in our northern sky; (2) the blue end of its spectrum is open,—it is only certainly known to contain hydrogen, the other metallic lines being exceedingly thin, thus indicating a small proportion of metallic vapours; while (3) *the hydrogen lines in this star are enormously distended*, showing that the chromosphere is largely composed of that element.

There are other bright stars of this class.

VIII. As types of γ the red stars may be quoted, the spectra of which are composed of channelled spaces and bands, and in which naturally the blue end is closed. Hence the reversing layers of these stars probably contain metalloids, or compounds, or both, in great quantity; and in their spectra not only is hydrogen absent, but the metallic lines are reduced in thickness and intensity, which in the light of V., *ante*, may indicate that the metallic vapours are being

associated. It is fair to assume that these stars are of a lower temperature than our sun.

In the same year, in a letter to M. Dumas, published in the 'Comptes Rendus,'* I again pointed out that, if we consider merely the scale of temperature, a celestial body with flutings in its spectrum would be cooler than one which had lines in its spectrum; and I also pointed out that, taking the considerable development of the blue end of the spectrum in white stars as contrasted with its feeble exhibition in stars like our sun, we had strong presumptive evidence to the effect that the stars like α Lyræ, with few lines in their spectra, were hotter than those resembling our sun, in which the number of lines was very much more considerable, and I added an inference from this: "plus une étoile est chaude, plus son spectre est simple." This related merely, as I have said before, to the consideration of one line of temperature.

Vogel's Classification.

In the year following my paper, the most considerable classification which has been put forward of late years was published by Dr. Vogel ('Astr. Nachr.,' No. 2000), who, basing his work on the previous types of Secchi, and also taking into account the inference I drew in my letter to Dumas, modified Secchi's types to a certain extent, but always along one line of temperature, the leading idea being, as I gather from many remarks made in Dunér's admirable memoir, to be referred to presently, that the classification is based upon descending temperatures, and that all the stars included in it are supposed at one time or other to *have had* a spectrum similar to that of α-Lyræ.†

This classification is as follows:—

* "Il semble que plus une étoile est chaude, plus son spectre est simple et que les éléments métalliques se font voir dans l'ordre de leurs poids atomiques. Ainsi nous avons:—

"(1) Des étoiles très brillantes, où nous ne voyons que l'hydrogène *en quantité énorme*, et le magnésium.

"(2) Des étoiles plus froides, comme notre soleil, où nous trovons:—

$$\mathrm{H + Mg + Na.}$$
$$\mathrm{H + Mg + Na + Ca,\quad Fe,\ \&c.;}$$

dans ces étoiles, pas de métalloïdes.

"(3) Des étoiles plus froides encore, dans lesquelles tous les éléments métalliques sont associés, où leurs lignes ne sont plus visibles, et où nous n'avons que les spectres des métalloïdes et des composés.

"(4) Plus une étoile est âgée, plus l'hydrogène libre disparaît; sur la terre, nous ne trouvons plus l'hydrogène en liberté."

† "Car selon la théorie il faudra que tôt ou tard toutes les étoiles de la première classe deviennent de la seconde, et celles-ci de la troisième."—(Dunér.)

Class I. *Spectra in which the Metallic Lines are extremely Faint or entirely Invisible.*—The most refrangible parts, blue and violet, are very vivid. The stars are white.

(*a.*) Spectra in which the lines of hydrogen are very strong.

(*b.*) Spectra in which the lines of hydrogen are wanting.

(*c.*) Spectra in which the lines of hydrogen and D_3 are bright.

Class II. *Spectra in which the Metallic Lines are Numerous and very Visible.*—The blue and violet are relatively weaker; in the red part there are sometimes faint bands. The colour of the star is clear bluish-white to deep reddish-yellow.

(*a.*) Spectra with numerous metallic lines, especially in the yellow and green. The lines of hydrogen are generally strong, but never as strong as in the stars of Class I. In some stars they are invisible, and then faint bands are generally seen in the red formed by very close lines.

(*b.*) Spectra in which besides dark lines and isolated bands there are several bright lines.

Class III. *Spectra in which besides the Metallic Lines there are numerous Dark Bands in all parts of the Spectrum, and the Blue and Violet are remarkably Faint.*—The stars are orange or red.

(*a.*) The dark bands are fainter towards the red.

(*b.*) The bands are very wide, and the principal are fainter towards the violet.

It is pointed out that if this classification be true, there must be links between all the classes given. Now it is perfectly obvious that if this classification includes in its view all the stars, and if there is a line of ascending as well as descending temperatures—that is to say, if some of the stars are increasing their temperatures, while others are diminishing them—the classification must give way.

It is not difficult to see, in the light of my communication to the Society of November 17th, that it has given way altogether, and principally on this wise.

The idea which underlies the classification is that a star of Class I on cooling becomes a star of Class II, and that a star of Class II has as it were a choice before it of passing to Class III*a* or Class III*b*. Thus under certain conditions its spectrum will take on the appearance of Secchi's third type, Class III*a* (Vogel); on certain other conditions it will take on the appearance of Secchi's fourth type, Class III*b* (Vogel). There is now, however, no doubt whatever that Secchi's Class III*a* represents stars in which the temperature is increasing, and with conditions not unlike those of the nebulæ—that is to say, the meteorites are discrete, and are on their way to form bodies of Class II and Class I by the ultimate vaporisation of all their meteoric constituents. There is also no doubt that the stars included in Class III*b* have had their day; that their tempera-

ture has been running down, until owing to reduction of temperature they are on the verge of invisibility brought about by the enormous absorption of carbon in their atmospheres.

Pechüle was the first to object to Vogel's classification, mainly on the ground that Secchi's types 3 and 4 had been improperly brought together; and my work has shown how very just his objection was, and how clear-sighted was his view as to the true position of stars of Class III*b*. I give the following extract from his memoir:—

"M. Vogel a proposé une classification suivant les diverses phases de refroidissement indiquées par les spectres, dans laquelle il fait des types III et IV de Secchi deux subdivisions d'une même classe, III*a* et III*b*. Mais je trouve certaines difficultés negatives contre cette classification relativement au rôle qu'y joue le III*b*. En effet, il est admis que le IV type de Secchi se distingue nettement du III type, non seulement par la position et la quantité des zones obscures, mais aussi par le fait très-remarquable, que les principales de ces zones sont bien définies et brusquement interrompues du côté du violette dans le III type, du côté du rouge dans le IV. Or, si le IV type doit représenter une des phases de refroidissement, par lesquelles passent les étoiles, on peut faire deux hypothèses. La première est que le spectre du IV type soit co-ordonné au spectre du III type, de manière qu'il ait des étoiles, qui passent de la phase représentée par le II type, à la phase représentée par le III type, et d'autres, qui passent directement du II type au IV. Mais cette hypothèse est inadmissible. Car on connaît de spectres entremédiaires entre le I et le II type, et entre le II et III; mais on ne connaît pas, à ce que je sache, de spectres du II type tendant au IV. Reste donc l'hypothèse, que la phase de refroidissement, représentée par le spectre du IV type, soit postérieure à la phase représentée par le III type, de manière que les spectres des étoiles passent du III au IV type. Si ce passage se fait peu à peu, il devrait avoir des spectres entremédiaires entre le III et le IV type; mais quoique Secchi par exemple le 17 Jan., 1868, ait déterminé le spectre de l'étoile 273 Schjell., comme semblant entremédiaire entre le III et le IV type, il l'a plus tard reconnu du IV type, et l'existence de spectres de III—IV type n'est nullement prouvée. On pourrait objecter que les étoiles du IV type sont peu nombreuses et en général si petites que leurs spectres sont difficiles à voir, et que par conséquent il pourrait y avoir parmi ces spectres quelques-uns, qui se rapprochassent du III type. Mais je réponds à cette remarque, que les spectres du III—IV type, indiquant une phase moins refroidie, devraient au contraire en général appartenir à des étoiles plus grandes que celles avant des spectres du IV type. Si on veut supposer que le passage du III au IV type se fasse subitement, ou par une catastrophe, pendant laquelle apparaissent des lignes brillantes, cettes supposition même

constituerait une différence physique bien plus distincte entre le III et le IV type qu' entre le II et le III; et le IV type représenterait une phase bien distincte, la dernière peut-être avant l'extinction totale. Le rôle physique du IV type est donc encore si mystérieux, que j'ai cru pouvoir encore me conformer à l'exemple de d'Arrest, en suivant la classification formelle de Secchi."—C. F. Pechüle, 'Expédition Danoise pour l'Observation du Passage de Vénus, 1882,' p. 25, (Copenhagen, J. H. Schultz, 1883).

II. Proposed New Grouping of all Celestial Bodies according to Temperature.

Having, then, gone over the various classifications of stars according to their spectra, I now proceed to consider the question of the classification of celestial bodies from a more advanced point of view. I pointed out in the year 1886 that the time had arrived when stars with increasing temperatures would require to be fundamentally distinguished from those with decreasing temperatures, but I did not then know that this was so easy to accomplish as it now appears to be ('Nature,' vol. 34, p. 228); and, as I have already stated, when we consider the question of classification at all, it is neither necessary nor desirable that we should limit ourselves to the stars; we must include the nebulæ and comets as well. Stellar variability should not introduce any difficulties, seeing that as a rule in its extremest form it is the passage from one spectrum to another, even if of a different type, owing to sudden changes of temperature.

In the first classification on these lines, which is certain to be modified as our knowledge gets more exact, it is desirable to keep the groups as small in number as possible; the groups being subsequently broken up into sub-groups, or, even into species, as the various minute changes in spectra brought about by variations of temperature are better made out.

For the purpose of making clear what follows, I here introduce from my paper of November 17th, the "temperature curve," on which is shown the distribution of nebulæ, comets, and of stars as divided into classes by Vogel, on the two arms of the curve.

On one arm of this we have those stages in the various heavenly bodies in which in each case the temperature is increasing, while on the other arm we have that other condition in which we get first vaporous combination, and then ultimately the formation of a crust due to the gradual cooling of the mass, in dark bodies like, say, the companion to Sirius. At the top we of course have that condition in which the highest temperature must be assumed to exist.

To begin, then, a more general classification with the lowest temperatures, it is known that the nebulæ and comets are distinguished

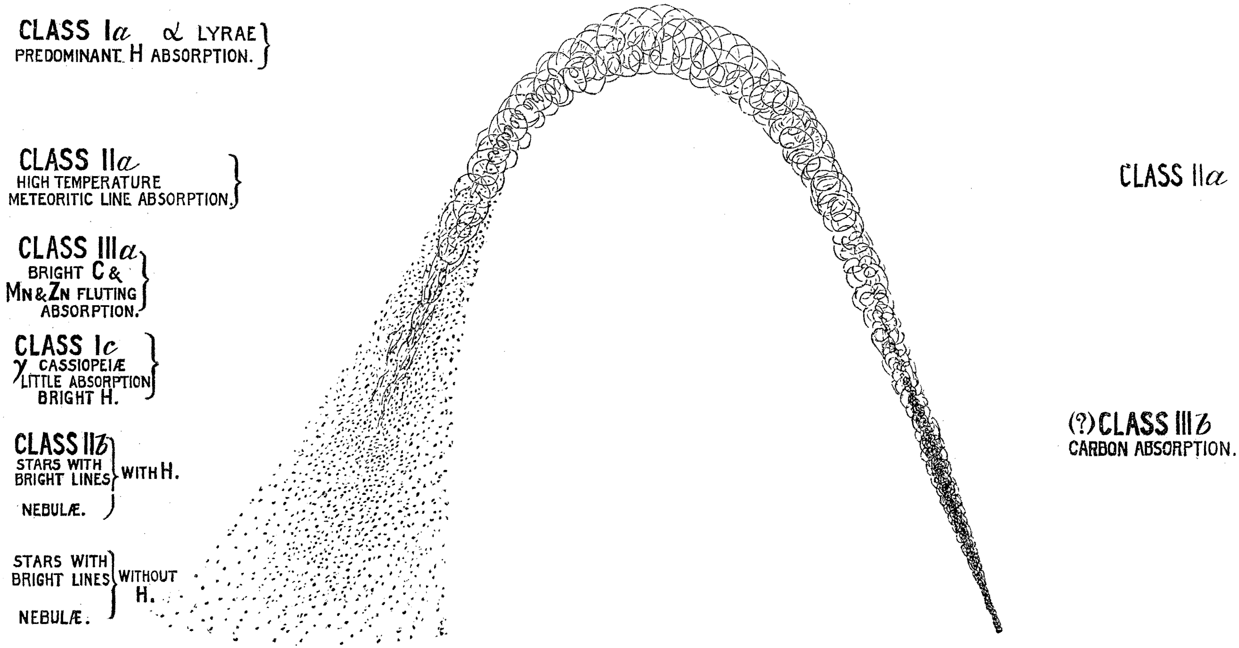

FIG. 4.—Temperature curve, showing the relative temperatures of the different orders of celestial bodies. The top of the curve represents the highest temperatures, and the bottom of each arm the lowest. On the left arm, the temperatures are increasing, on the right they are decreasing. The diagram shows the relative temperatures of Vogel's classes.

from most stars by the fact that we get evidence of radiation alone, or almost alone so far as we know. Absorption has been suspected in the spectra of some nebulæ,* and has been observed beyond all doubt in some comets.† But there are some stars in which we also get radiation, accompanied by certain absorption phenomena. But there is no difficulty in showing that nebulæ and comets are more special on account of their bright lines than on account of their absorption bands. I have already shown that in all probability the stars with bright lines are most closely allied with nebulæ. Indeed, it seems as if they are very nearly akin to those condensations in nebulæ, showing an undoubted olivine and hydrogen spectrum, which gave them the appearance of resolvability. It seems, also, highly probable that future observations with instruments of great light-collecting power, will show that in nebulæ, the spectra of which are recorded as continuous, lines including the remnants of some of the carbon flutings, which there is good reason to believe have already been traced in the spectra of bright line stars, are also present. From this point of view, the various recorded observations of regions of different colour in certain nebulæ acquire an additional interest. It is also clear that since the only real difference between comets and other meteor swarms of equal denseness is that the former are in motion round the centre of our system, comets whether at aphelion or at perihelion will fall into this group. We may, therefore, form the first group of bodies which are distinguished by the presence of bright lines or flutings in the spectrum.

The great distinction between the first group and the second would be that evidences of absorption now become prominent, and side by side with the bright flutings of carbon and occasionally the lines of hydrogen we have well-developed fluting absorption.

The second group, therefore, is distinguished from the first by mixed flutings as well as lines in the spectrum.

* "Nebula [No. 117, 51 h. 32 M. R.A. 0 h. 35 m. 5·3 s.; N.P.D. 49° 54′ 12·7″. Very, very bright; large, round; pretty suddenly much brighter in the middle].—This small but bright companion of the great nebula in Andromeda presents a spectrum exactly similar to that of 31 M. [the great nebula in Andromeda]. The spectrum appears to end abruptly in the orange; and throughout its length is not uniform, but is evidently crossed either by lines of absorption or by bright lines."—(Huggins, 'Phil. Trans.,' vol. 154, p. 441.)

† "A dark band was noticed at wave-length 567·9."—(Copeland, "Comet III, 1881," 'Copernicus,' vol. 2, p. 226.)

"May 20.—With none of these dispersions could any bright bands, properly so-called, be distinguished; but two faint broad *dark* bands, or what gave that impression, crossed the spectrum. . . . A third dark band was suspected near D on the blue side of that line."—(Maunder, "Comet *a*, 1882 (Wells)," 'Greenwich Spectroscopic Observations,' 1882, p. 34.)

"The dark bands were observed again, and their wave-lengths measured on May 31."—(*Ibid.*, p. 35.)

The passage from the second group to the third brings us to those bodies which are increasing their temperature, in which radiation and fluting absorption have given place to line absorption.

At present, the observations already accumulated have not been discussed in such a way as to enable us to state very definitely the exact retreat of the absorption—by which I mean the exact order in which the absorption lines fade out from the first members to the last in the group. We know generally that the earlier bodies will contain the line absorption of those substances of which we get a paramount fluting absorption in the prior group. We also know generally that the absorption of hydrogen will increase while the other diminishes.

The next group—the fourth, brings us to the stage of highest temperature, to stars like α Lyræ; and the division between this group and the prior one must be more or less arbitrary, and cannot at present be defined. One thing, however, is quite clear, that no celestial body without all the ultra-violet lines of hydrogen discovered by Dr. Huggins can claim to belong to it.

We have now arrived at the culminating point of temperature, and now pass to the descending arm of the curve. The fifth group, therefore, will contain those bodies in which the hydrogen lines begin to decrease in intensity, and other absorptions to take place in consequence of reduction of temperature.

One of the most interesting problems of the future will be to watch what happens in bodies along the descending scale, as compared with what happens to the bodies in Group III, on the ascending one. But it seems fair to assume that physical and chemical combinations will now have an opportunity of taking place, thereby changing the constituents of the atmosphere; that at first with every decrease of temperature an increase in the absorption lines may be expected, but it will be unlikely that the coolest bodies in this group will resemble the first one in Group III.

The next group, the sixth, is Secchi's type IV, and Vogel's Class III*b*, its distinct characteristics being the absorption flutings of carbon. The species of which it will ultimately be composed are already apparently shadowed forth in the map which accompanies Dunér's volume, and they will evidently be subsequently differentiated by the gradual addition of other absorptions to that of carbon, while at the same time the absorption of carbon gets less and less distinct.

To sum up, then, the classification I propose consists of the following groups:—

Group I.—Radiation lines and flutings predominant. Absorption beginning in the last species.

Group II.—Mixed radiation and absorption predominant.

Group III.—Line absorption predominant, with *increasing* tem-

perature. The various species will be marked by increasing simplicity of spectrum.

Group IV.—Simplest line absorption predominant.

Group V.—Line absorption predominant, with *decreasing* temperature. The various species will be marked by decreasing complexity of spectrum.

Group VI.—Carbon absorption predominant.

Group VII.—Extinction of luminosity.

It will be seen from the above grouping that there are several fundamental departures from previous classifications, especially that of Vogel.

The presence of the bright flutings of carbon associated with dark metallic flutings in the second group, and the presence of only absorbing carbon in the sixth, appears to be a matter of fundamental importance, and to entirely invalidate the view that both groups (the equivalents of III*a* and III*b* of Vogel) are produced from the same mass of matter on cooling.

This point has already been dwelt upon by Pechüle.

Another point of considerable variation is the separation of stars with small absorption into such widely different groups as the first and fourth, whereas Vogel classifies them together on the ground of the small absorption in the visible part of the spectrum. But that this classification is unsound is demonstrated by the fact that in these stars, such as γ Cassiopeiæ and β Lyræ, we have intense variability. We have bright hydrogen lines instead of inordinately thick dark ones; and on other grounds, which I shall take a subsequent opportunity of enlarging upon, it is clear that the physical conditions of these bodies must be as different as they pretty well can be.

It will be seen also that, with our present knowledge, it is very difficult to separate those stars the grouping of which is determined by line absorption into the Groups III and V, for the reason that so far, seeing that only one line of temperature, and that a descending one, has been considered, no efforts have been made to establish the necessary criteria. I noted this point in the paper to which I have already referred in connexion with the provisional curve.

Part III.—Sub-Groups and Species of Group I.

I. Sub-Group. Nebulæ.

Having, in the preceding part of this memoir, attempted to give a general idea of that grouping of celestial bodies which in my opinion best accords with our present knowledge, and which has been based upon the assumed meteoric origin of all of them, I now proceed to test the hypothesis further by showing how it bears the strain put

upon it when, in addition to furnishing us with a general grouping, it is used to indicate how the groups should be still further divided, and what specific differences may be expected.

The presence or absence of carbon will divide this group into two main sub-groups.

The first will contain those nebulæ in which only the spectrum of the meteoric constituents is observed with or without the spectrum of hydrogen added.

It will also contain those bodies in which the nebula spectrum gets almost masked by a continuous one, such as Comets 1866 and 1867, and the great nebula in Andromeda.

In the second sub-group will be more condensed swarms still, in which, one by one, new lines are added to the spectra, and carbon makes its appearance; while probably the last species in this sub-group would be bodies represented by γ Cassiopeiæ.

Species of Nebulæ.

I have elsewhere referred to the extreme difficulty of spectroscopic discrimination in the case of the meteor swarms which are just passing from the first stage of condensation, and it may well be that we shall have to wait for many years before a true spectroscopic classification of the various aggregations which I have indicated, can be made.

It is clear from what has gone before that in each stage of evolution there will be very various surfaces and loci of collision in certain parts of all the swarms, and we have already seen that even in the nebulosities discovered by Sir Wm. Herschel, which represent possibly a very inchoate condition, there are bright portions here and there.

If the conditions are such in the highly elaborated swarms and in the nebulosities that the number of collisions in any region per cubic million miles is identical, the spectroscope will give us the same result. In the classification of the nebulæ, therefore, the spectroscope must cede to the telescope when the dynamical laws, which must influence the interior movements of meteoric swarms, have been fully worked out. The spectroscope, however, is certainly at one with the telescope in pointing out that the so-called planetary nebulæ are among the very earliest forms—those in which the collisions are most restricted in the colliding regions. The colour of these bodies is blue tinged with green; they do not appear to have that milkiness which generally attaches to nebulæ, and the bright nebulous lines are seen in some cases absolutely without any trace of continuous spectrum. In higher stages the continuous spectrum comes in, and in higher stages still possibly also the bands of carbon; for in many cases Dr. Huggins in his important observations has recorded the weakness

of the spectrum in the red, or in other words the strengthening of the spectrum in the green and blue, exactly where the carbon bands lie.

But in all the bodies of Group I which possess forms visible to us in the telescope, it would seem proper that their classification should depend mainly—at present at all events—upon their telescopic appearance, and there is very little doubt that a few years' labour with the new point of view in the mind of observers armed with sufficient optical power, will enable us to make a tremendous stride in this direction; but it seems already that this must not be done without spectroscopic aid. For instance, if what I have previously suggested as to the possible origin of the planetary nebulæ be accepted, it is clear that in those which give us the purest spectrum of lines—one in which there is the minimum of continuous spectrum—we find the starting point of the combined telescopic and spectroscopic classification, and the line to be followed will be that in which, *cæteris paribus*, we get proofs of more and more condensation and, therefore, more and more collisions, and therefore higher and higher temperatures, and therefore greater complexity in the spectrum until at length "stars" are reached.

When true stars are reached those in a cluster may appear nebulous in the telescope in consequence of its distance; the spectroscope must give us indications of absorption.

It is not necessary in this connexion, therefore, to refer to undoubted star clusters, as the presence of absorption will place them in another group; but the remark may be made that it is not likely that future research will indicate that new groupings of stars, such as Sir Wm. Herschel suggests in his paper on the breaking up of the Milky Way, will differ in any essential particular from the successive groupings of meteorites which are watched in the nebulæ. Space and gravitation being as they are, it is not necessary to assume that any difference of kind need exist in the groupings formed by stars and meteoric dust; indeed there is much evidence to the contrary.

II. Sub-Group. Bright-line Stars.

It might appear at first sight that the distribution of bright-line stars among various species should be very easy, since a constant rise of temperature should bring out more and more lines, so that species might be based upon complexity of spectrum merely.

But this is not so, for the reason that the few observations already recorded, although they point to the existence of carbon bands, do not enable us to say exactly how far the masking process is valid. Hence in the present communication I content myself by giving some details relating to masking, and the results of the discussions, so far as they

have gone, in the case of each star. I shall return to the line of evolution of these bodies in a later paper.

Masking of Radiation Effects produced by Variations of Interspacing.

I have already stated that carbon bands are apt to mask the appearance of other spectral phenomena in the region of the spectrum in which they lie. In this way we can not only account for the apparent absence of the first manganese fluting, while the second one is visible, but it is even possible to use this method to determine which bands of carbon are actually present. There is another kind of masking effect produced in a different way, and this shows itself in connexion with sodium. It is well known that when the temperature is low, D is seen alone, and if seen in connexion with continuous spectrum the continuous spectrum is crossed by either dark or bright D, according to the existing circumstances.

I showed some years ago that the green line of sodium (but not the red one) is really visible when sodium is burned in the bunsen burner. It is, however, very much brighter when higher temperatures are used, although when bright it does not absorb in the way the line D does.

Now, if we imagine a swarm of meteorites such that in the line of sight the areas of meteorite and interspace are equal, half the area will show D absorbed, and the other half D bright; and in the resulting spectrum D will have disappeared, on account of the equality, or nearly equality, of the radiation added to the absorption of the continuous spectrum. The light from the interspace just fills up and obliterates the absorption.

But if the temperature is such that the green line is seen as well as D; in consequence of its poor absorbing effect there will be no dark line corresponding to it in the resulting spectrum, but the bright green line from the interspace will be superposed on the continuous spectrum, and we shall get the apparently paradoxical result of the green line of sodium visible while D is absent. This condition can be partly reproduced in the laboratory by volatilising a small piece of sodium between the poles of an electric lamp. The green line will be seen bright, while D is dark.

In the bodies in which these phenomena apparently occur—for so far I have found no other origin for the lines recorded as 569, 570, and 571, the wave-length of the green sodium line being 5687—such as Wolf and Rayet's three stars in Cygnus and in γ Argûs, the continuous variability of D is one of the facts most clearly brought out by the observations, and it is obvious that this should follow if from any cause any variation takes place in the distance between the meteorites.

In all meteoric glows which have been observed in the laboratory, not only D but the green line has been seen constantly bright,

while we know that in Comet Wells most of the luminosity at a certain stage of the comet's history was produced by sodium. It is therefore extremely probable that the view above put forward must be taken as an explanation of the absence of D when not seen, rather than an abnormal chemical constitution of the meteorites—that is to say, one in which sodium is absent. This may even explain the fact that up to the present time the D line of sodium has not been recorded in the spectrum of any nebula.

[*Note.*—In the lecture the author here referred to the spectrum of o Ceti, as photographed by Professor Pickering for the Henry Draper Memorial, the slide having been kindly placed at his disposal by the Council of the Royal Astronomical Society. All the bright hydrogen lines in the violet and ultra-violet are shown in the photograph, with the exception of the one which is nearly coincident with H. The apparent absence of this line is in all probability due to the masking effect of the absorption line of calcium. In this case, then, it appears that the calcium vapour was outside the hot hydrogen, and this therefore was being given off by the meteorites at the time.—April 18.]

Detailed Discussions of the Spectra of some Bright-line Stars.

These things then being premised, I now submit some maps to the Society illustrating this part of the inquiry, although it will be some time before my investigations on the bright-line stars are finished. These maps will indicate the way in which the problem is being attacked, and the results already obtained. To help us in the work we have first of all those lines of substances known to exist in meteorites *which are visible at the lowest temperatures which we can command in the laboratory.* We have also the results of the carbon work to which reference was made in the previous paper; and then we have the lines which have been seen, although their wave-lengths have in no case been absolutely determined in consequence of the extreme difficulty of the observation, both in stars and in comets, which I hold to be almost identical in structure.

In the case of each star the lines which have been recorded in its spectrum are plotted in the way indicated in the maps. The general result is that when we take into account the low temperature radiation, which we learn from the laboratory work, not only can we account for the existence of the lines which have been observed, but apparent absorptions in most cases are shown to be coincident with the part of the spectrum in front of a bright fluting.

A continuation of this line of thought shows us also that, when in these stars the spectrum is seen far into the blue, the luminosity really proceeds first from the carbon fluting, and in the hotter stars, from the hydrocarbon one, which is still more refrangible, in addition. In the stars which have been examined so far, the dark parts of the

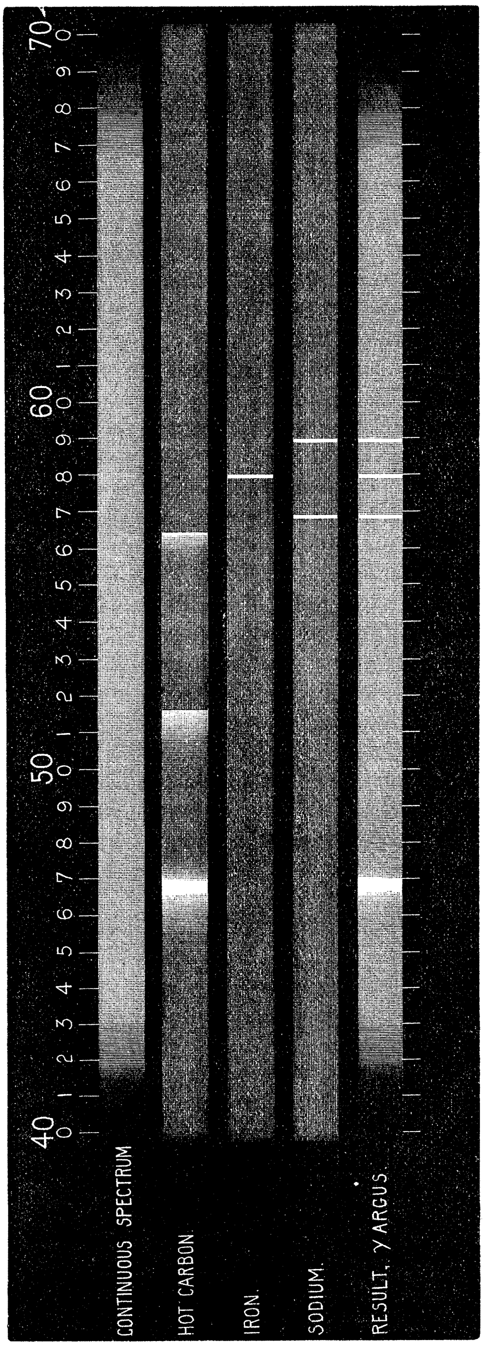

FIG. 5 (γ Argus).—Map showing the probable origin of the spectrum of γ Argus.

spectrum, which at first sight appear due to absorption, are shown to be most likely caused by defect of radiation in that part of the spectrum between the blue end of the continuous spectrum from the meteorites, and the bright band of carbon.

All the observations, it would appear, can be explained on the assumption of low temperature.

Notes on the Maps.

γ *Argus.*—R.A. 8 h. 5 m. 56 s., Dec. $-46°$ 59·5′. Respighi and myself observed the bright lines in the spectrum of this star at Madras in 1871. No measurements were made of the wave-lengths of the lines, which were observed by Ellery at Melbourne in 1879, and given as 5760, 5648, and 4682. Other bright lines were suspected.

Copeland examined and mapped the spectrum of this star while in the Andes in 1883. His wave-lengths are 580·9, 566·8, 464·6, and a fainter line at 590. The continuous spectrum extends from 420 to 675, the lines being seen bright on this, but no mention is made by either Ellery or Copeland of absorption of any kind. The bright lines at 590 and 566·8 are most probably the lines of sodium, 5890—95 and 5687; the 580·9 line is probably the 579 strongest low-temperature line of iron; and the 468 (464·6 Copeland) is due to the carbon fluting, which has its maximum intensity at 468, the other carbon flutings at 517 and 564, being rendered invisible to Copeland by the bright continuous spectrum, although Ellery's measurement of 564·8 is most probably the carbon band at that point. The 517 carbon may have been seen by Ellery, for although no measurements are given he saw other bright lines or spaces. The dark band 474 to 486 seen in the Cygnus stars, Argelander-Oeltzen 17681, and Lalande 13412, being due to the shortness of the continuous spectrum, and the appearance of the carbon band beyond the blue end, is not seen in this star, because it has a long continuous spectrum.

The bright lines seen in it are due to low temperature sodium and iron, and to carbon flutings on a bright continuous spectrum.

Respighi's observations are given in 'Comptes Rendus,' vol. 74, p. 516; Ellery's results are given in a letter to 'The Observatory' vol. 2, p. 418; Copeland's are published in 'Copernicus,' vol. 3, p. 204.

Argelander-Oeltzen 17681.—Two observers have examined and mapped the spectrum of this star, Dr. Vogel at Potsdam, and Professor Pickering at Harvard College. Both give the wave-lengths of the lines observed, while in addition Dr. Vogel publishes a sketch of the spectrum as it appeared to him.

Vogel's strongest line is at 581. This Pickering measures as

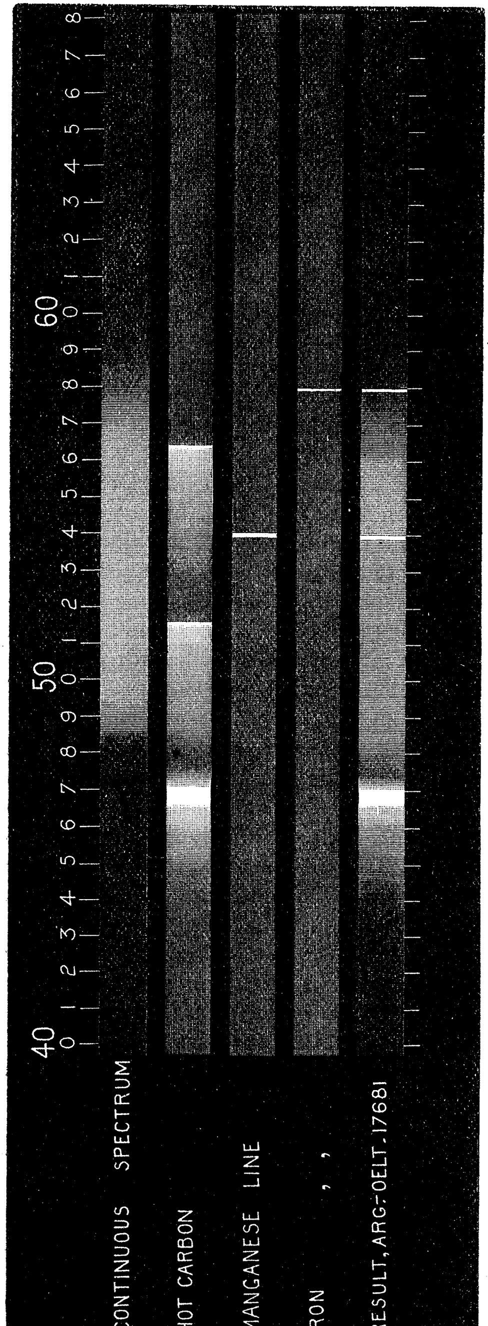

FIG. 6.—Map showing the probable origin of the spectrum of Argelander-Oeltzen 17681.

580—585, evidently when using a wide slit, while in a later account of his observations he fixes the wave-length at 580. The line is probably 579, the strongest line of iron at a low temperature. Vogel mentions a bright band extending from 470 to 461 with a maximum between these limits. Pickering measures this as commencing at 473. This band is evidently the bright band of carbon commencing at 474, with a maximum about 468 as observed and photographed at Kensington. Between this band and 486 Vogel has shown a dark band in the spectrum. This appearance is due not to any absorption but to the continuous spectrum being short, ending evidently at 486, while the bright carbon appearing beyond this in the blue, leaves a dark band due to absence of radiation.

Vogel has not noticed any other bright lines, but Pickering "suspected" a brightening at 540. This would be the only line of manganese which appears in the bunsen burner. Vogel may have noticed this line and yet not given any wave-length of it in his list, just as he indicates one bright line in 2nd Cygnus, and two bright lines in 3rd Cygnus in his light curves of those stars, without mentioning them in any list of bright lines observed.

Pickering suspected the presence of several other lines, but was unable to obtain any measurements of them.

Vogel's results are given in the 'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 15, and in the sketch at the end of that number.

Pickering's are in 'The Observatory,' vol. 4, p. 82; the 'American Journal of Science and Art,' No. 118, 1880; 'Copernicus,' vol. 1, p. 86; and 'Astronomische Nachrichten,' 2376.

Lalande 13412—Both Vogel and Pickering have observed the spectrum of this star and have measured the wave-lengths of the bright lines.

Vogel gives a sketch of the spectrum as well as a list of wave-lengths.

Vogel mentions a dark band at the blue end of the spectrum, and gives the wave-length in his sketch as from 486 to 473.

Both observers measure the bright 486 hydrogen (F) line.

Vogel measures a bright line at 540, while Pickering's measure is 545; but Pickering in another star, Arg.-Oeltzen 17681, has measured a line at 540, so there can be little doubt that is the correct wave-length.

Vogel measures a line at 581, but this has not been noticed by Pickering.

The bright part of the spectrum extending from 473 towards the blue with its maximum at 468 is, I would again suggest, the carbon band appearing beyond the continuous spectrum, the rest of the carbon

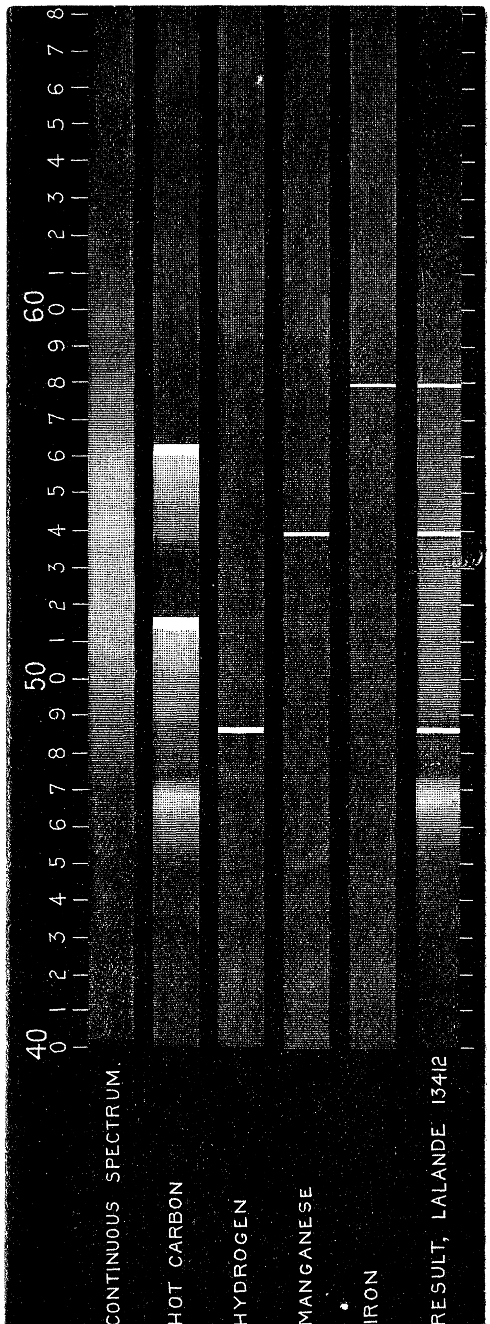

FIG. 7.—Map showing the probable origin of the spectrum of Lalande 13412.

being cut out by the continuous spectrum, although 564 asserts itself by a brightening of the spectrum at that wave-length in Vogel's sketch, and by a rise in his light curve.

The line at 540 is the only line of manganese visible at the temperature of the bunsen burner, while the 581 measurement of Vogel is in all probability the 579 line, the strongest line of iron visible at low temperatures.

In this star, therefore, we have continuous spectrum from the meteorites, and carbon bands, one of them appearing beyond the continuous spectrum in the blue as a bright band; bright lines of hydrogen, manganese, and iron being superposed on both. There is no absorption of any kind, the apparent dark band being due to defect of radiation, as in Argelander-Oeltzen 17681.

Vogel's results are given in the 'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 17.

Pickering's are published in the 'Astronomische Nachrichten,' No. 2376; 'Science,' No. 41; and quoted in 'Copernicus,' vol. 1, p. 140.

1*st Cygnus*.—B.D. + 35°, No. 4001.—The spectrum of this star was observed by Messrs. Wolf and Rayet in 1867, but no measurements of the positions of the bright lines were then published. In the same paper, however, they give the measurements of the positions of the bright lines in 2nd Cygnus (B.D. + 35°, No. 4013) which they observed about the same time, and since the bright lines were similar in these stars, the wave-lengths 581, 573, 540, and 470, may be taken as indicating the positions of the lines in 1st Cygnus. They also observed dark spaces between 470 and 486, and on the blue side of 573.

Dr. Vogel, of Potsdam, examined the spectrum of this star, and has published his results in three ways, as a list of bright lines given in wave-lengths; as a sketch of the spectrum as it appeared to him, and as a curve showing the intensity of the light throughout the spectrum.

His wave-lengths are 583, 571, 541, 486 (hydrogen F) for lines, and a bright band from 470 to 465, with its maximum at 468.

The sketch confirms these lines, while the light curve adds three others to them at wave-lengths 507, 527, and 558. He also gives an absorption-band between the 486 line and 470 band, and in his sketch gives a darkening on the blue side of 570, this being also indicated in the light curve. These dark spaces agree with the dark spaces observed by Messrs. Wolf and Rayet.

The bright band, with its maximum at 468, is the bright carbon fluting commencing at 474, and extending towards the blue with its maximum at 468, as photographed at Kensington, and the dark space

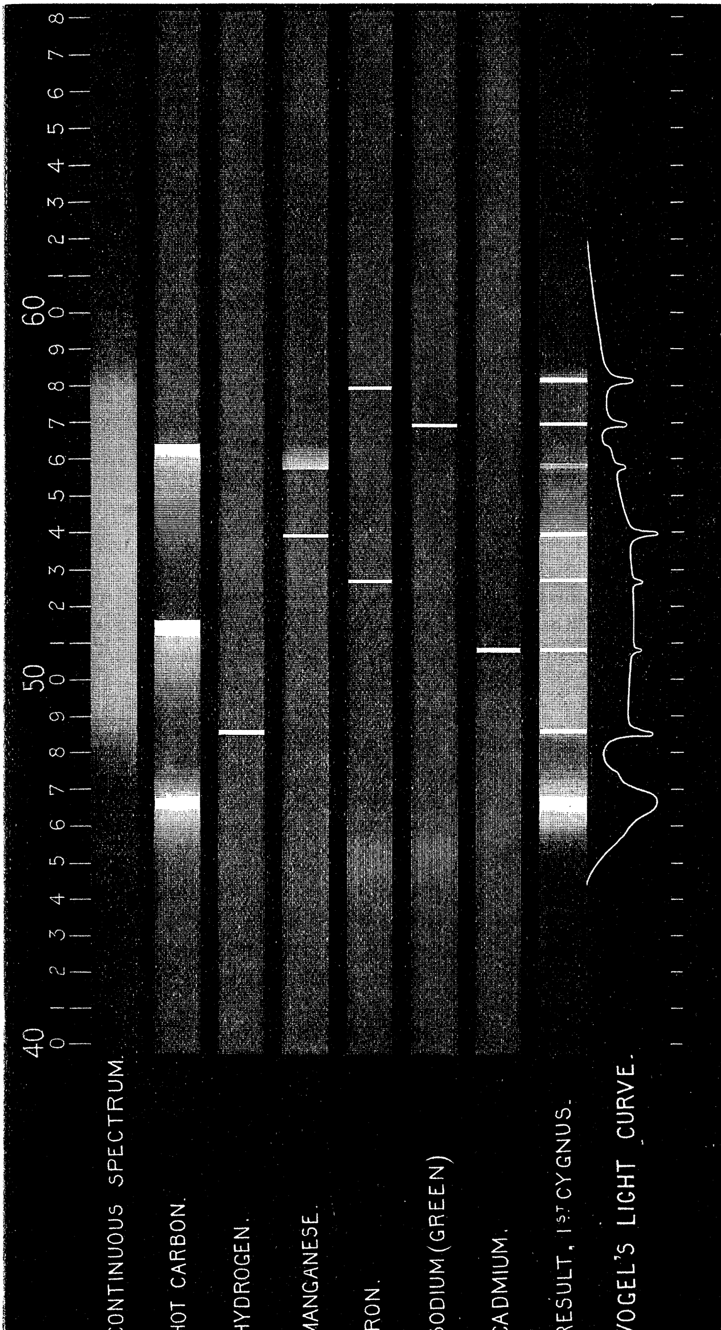

Fig. 8.—Map showing the probable origin of the spectrum of Wolf's and Rayet's 1st star in Cygnus.

between this and the 486 line is not due to absorption of the light from the meteorites by any vapour around them, but rather to the absence of any radiation except that from the meteorites themselves at this part of the spectrum.

The carbon at 564 raises the curve at that point, and this brightness with the bright 570 line produces the appearance of a dark space between those wave-lengths, the band being simply due to the contrast of a bright fluting and a bright line lying some distance apart on a faint continuous spectrum. There is therefore no absorption of any kind in this star, all the dark bands being due to absence of radiation.

Of the bright lines two, the 540 and the 558, are due to manganese, 540 being the manganese line visible in the bunsen, while 558 is the strongest of the low temperature flutings of manganese. The line at 581, or thereabouts, is most probably the strongest low temperature line of iron. The line at 569 is most probably the green sodium line, while the 486 line is assigned by Vogel to hydrogen. The faint line at 507 has been observed in the flame spectra of several meteorites, and is in the exact position of the strongest line of cadmium at the temperature of the bunsen burner.

This star, therefore, gives a spectrum, which is short and faintly continuous, due to radiation of meteorites, but has light from carbon added, with a separate band appearing in the blue; while the strongest low-temperature lines of manganese, iron, and cadmium, with a strong manganese fluting, and the green sodium line, appear bright on the continuous spectrum. There is no absorption of any kind.

Wolf and Rayet's discovery of bright lines is recorded in 'Comptes Rendus,' vol. 65, p. 292, and confirmed in vol. 68, p. 1470, vol. 69, pp. 39 and 163. Vogel's observations are given in the 'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 17, and shown in a sketch at the end of that number.

2nd Cygnus.—B.D. + 35°, No. 4013.—Messrs. Wolf and Rayet, in 1867, first observed the spectrum of this star, and measured the positions of the bright lines. Micrometer readings and reference lines are given by them from which a wave-length curve has been constructed. The wave-lengths of the bright lines in the star thus ascertained are: 581 (γ), 573 (β), 540 (δ), and 470 (α); the relative intensities being shown by the Greek letters. They state that:—

"La ligne β est suivie d'un espace obscur; un autre espace très-sombre précède α."

Vogel afterwards examined the spectrum, measured the positions and ascertained the wave-lengths of the bright lines, drew a sketch

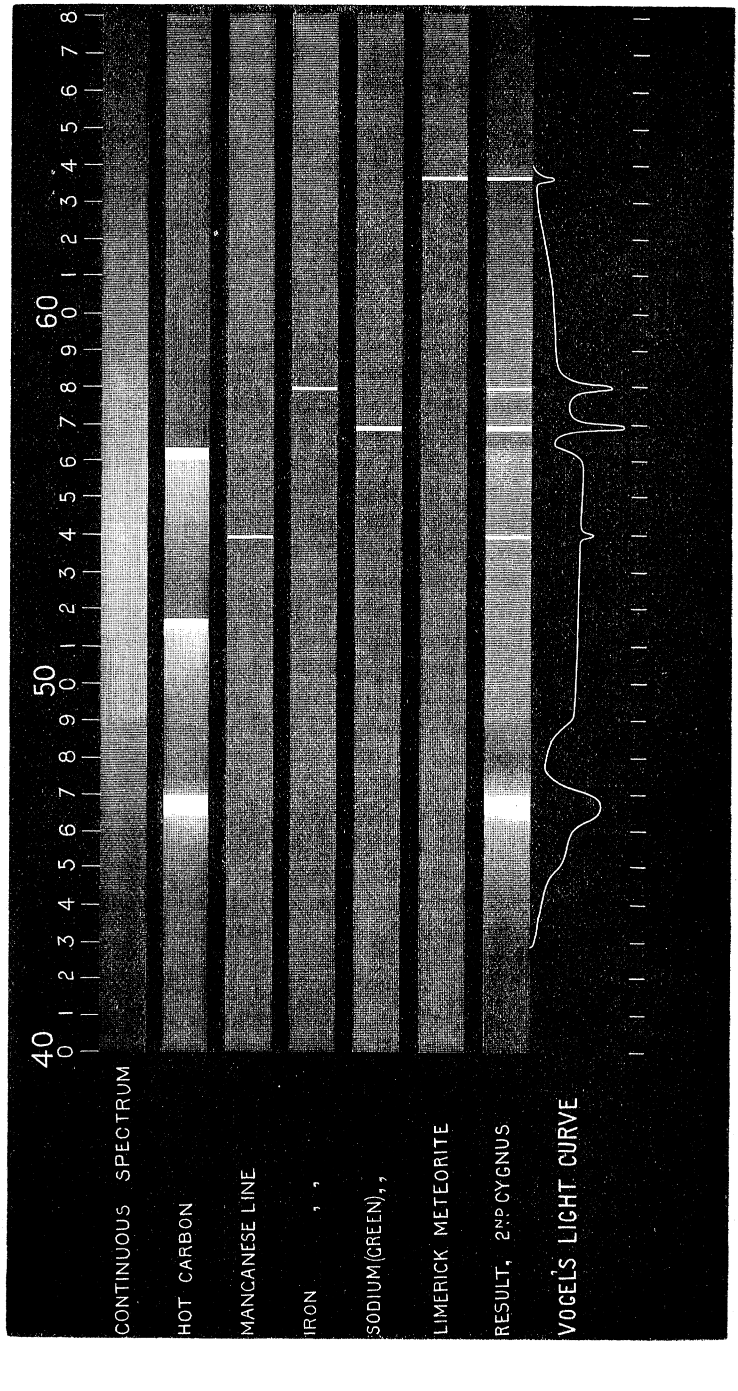

FIG. 9.—Map showing the probable origin of the spectrum of Wolf's and Rayet's 2nd star in Cygnus.

of the spectrum as it appeared to him, and a curve showing the variation of intensity of the light throughout the spectrum.

The wave-lengths given by Vogel are 582 and 570, and a band with its brightest part at 464, fading off in both directions and according to the sketch having its red limit at 473. In the light curve Vogel not only shows the 582 and 570 lines, but also bright lines in positions which by a curve have been found to correspond to wave-lengths 540 and 636. Vogel indicates in his sketch a dark band extending from 486 to the bright band 473, and an apparent absorption on the blue side of the 570 line, this absorption being ended at 564. These two bands agree in position with the dark spaces observed by Messrs. Wolf and Rayet. The bright band in the blue at 473 is most probably the carbon band appearing bright upon a faint continuous spectrum, this producing the apparent absorption from 486 to 473. If the bright carbon really accounts for the appearance of a (contrast) dark band between the bright 570 and 564 in this star, all the apparent absorption is explained as due to contrast of bright bands on a fainter continuous spectrum due to red-hot meteorites.

The line at 540 is the only line of manganese visible in the bunsen burner, and the 580 line is the strongest low-temperature iron line. The 570 line is most probably the green sodium line 569, the absence of the yellow sodium being explained by the half-and-half absorption and radiation mentioned in the discussion of the causes which mask and prevent the appearance of the lines in a spectrum.

The line at 636 is in the red just at the end of the continuous spectrum, and as yet no origin has been found for it, although it has been observed as a bright line in the Limerick meteorite at the temperature of the oxyhydrogen blowpipe.

This star therefore gives a continuous spectrum due to radiation from meteorites, and on this we get bright carbon (with one carbon band appearing separate as being beyond the continuous spectrum in the blue), with bright lines of iron, manganese, sodium, and some as yet undetermined substance giving a line at 636 in the oxyhydrogen blowpipe.

Wolf and Rayet's results are given in the 'Comptes Rendus,' vol. 65, p. 292.

Dr. Vogel's are from the 'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 19.

3rd Cygnus.—B.D. + 36°, No. 3956.—This is one of the three stars observed by Messrs. Wolf and Rayet, in 1867, as having bright lines in their spectra, but they do not give measurements of the wave-lengths of the lines. They give, however, lines at 581, 573, 540, and 470, as present in 2nd Cygnus, so we can reasonably infer these wave-

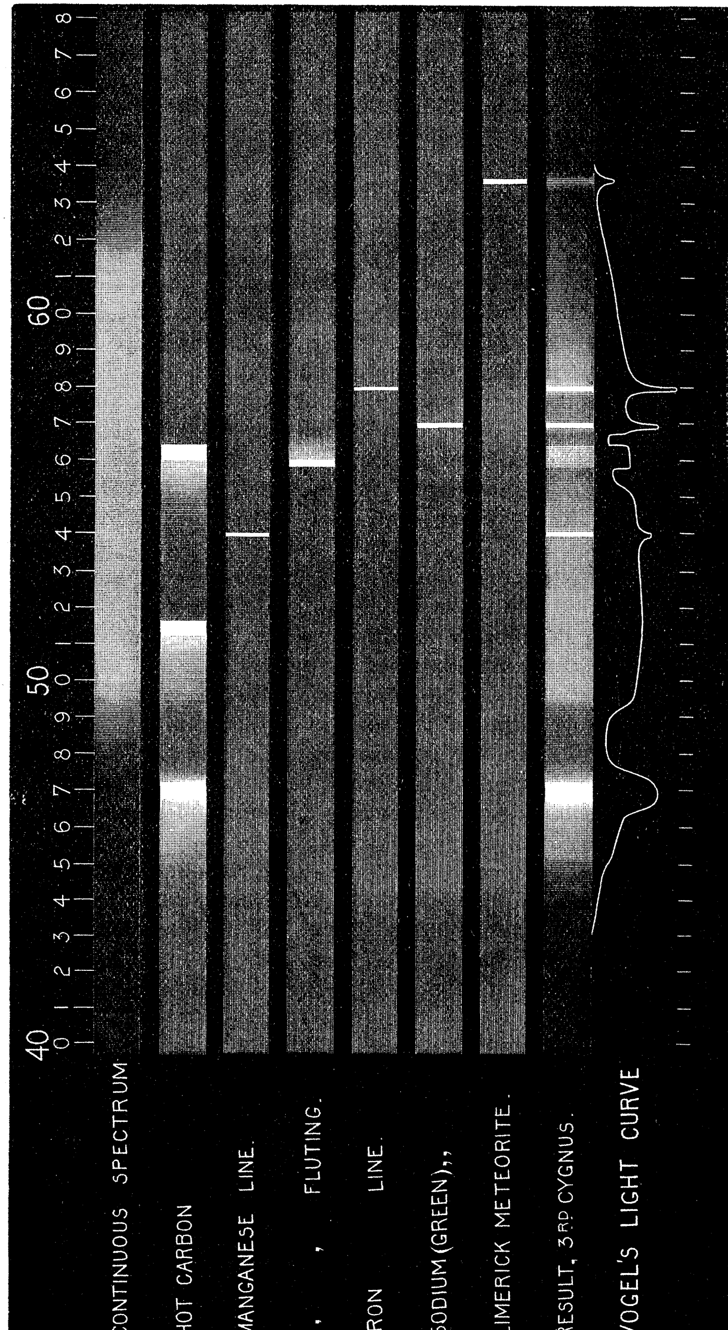

FIG. 10.—Map showing the probable origin of the spectrum of Wolf's and Rayet's 3rd star in Cygnus.

lengths are fairly correct for this star, especially as Dr. Vogel's measurements of the bright lines are 582 and 569 with a bright band commencing at 468. Vogel, in addition to his wave-lengths, also gives a sketch of the spectrum in which he shows the bright 540 line; and a light curve showing the variations of the intensity of the light throughout the spectrum, in which curve he indicates all the lines above-mentioned, and an additional bright line at 636.

The sketch shows also a dark band in the spectrum from about 488 to 473, another from 553 to 556, and a third on the blue side of 570 extending from that line to 564. These dark spaces are confirmed in the light curve, and two of them, 488 to 473, and 570 to 564, agree with the dark spaces observed by Messrs. Wolf and Rayet in 2nd Cygnus.

The bright band at 470 is the carbon band in the blue commencing at 474, with its maximum at about 468, as observed and photographed at Kensington, and between this and 488 is the dark space which is most probably due to absence of radiation rather than to any absorption. The carbon at 517 asserts itself by a rise in the light curve at that point, while the 564 carbon is also seen to produce a sudden rise in the curve.

The 564 carbon and the 558 manganese fluting uniting produce a bright band of light between those wave-lengths, and this on the faint continuous spectrum produces an apparent dark space on each side, thus accounting for the dark appearances at 554—557 and 564—570, these being contrast appearances only and not absorption bands. The 540 line is the manganese line seen in the bunsen burner. The line at 570 is most probably the green sodium line, the yellow sodium being rendered invisible by the half-and-half absorption and radiation masking previously mentioned. The 580 line is most probably the strongest low-temperature line of iron, 579; while the 636 line has been seen in the Limerick meteorite when heated in the oxyhydrogen flame, although its origin has not yet been determined.

In this star, therefore, we have continuous spectrum from the meteorites; carbon bands at 474, 517, and 564, rendering themselves apparent in the light curve; the low-temperature manganese line and the strongest manganese fluting; the low-temperature iron line, the green sodium, and a line the origin of which is unknown, all appearing bright. There is no absorption.

Vogel's results are given in the 'Publicationen des Astrophysikalischen Observatoriums zu Potsdam,' vol. 4, No. 14, p. 19.

γ Cassiopeiæ.—Secchi at the very commencement of his work at stellar spectra noticed the bright lines in the spectrum of this star. He records the presence of bright lines of hydrogen and of the bright

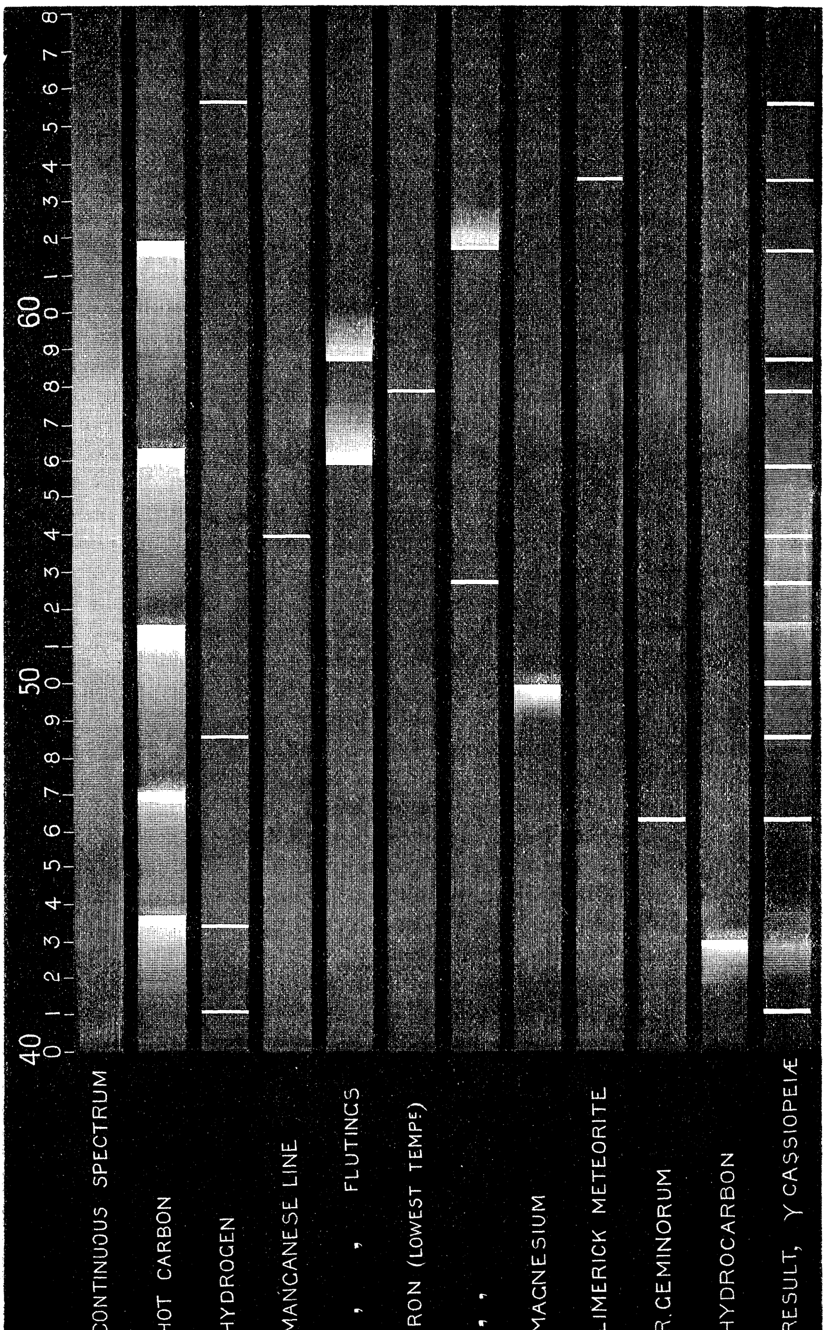

Fig. 11 (γ Cassiopeiæ).—Map showing the probable origin of the spectrum of γ Cassiopeiæ.

D_3 line. ('Bull. Météorol. du Collège Romain,' 31 Juillet, 1863, p. 108.)

Vogel on June 19th, 1872 observed a bright line in the greenish-blue 486, and one in the yellow which he assumes to be D_3. An absorption band was also noticed in the red, but its wave-length was not determined. ('Both. Beob.,' Heft 2, p. 29.)

Great stress was laid on the fact that the bright lines died out between 1874 and 1883, when they were observed by Gothard, but on December 26th, 1879, C was noted as "superbly visible" by Lord Lindsay, J. G. Löhse and Dr. R. Copeland, and two bright lines, one evidently F, observed on October 28th, 1877. No mention is made of C in the records of the observation. ('Monthly Notices of the R. Astron. Soc.,' vol. 47, p. 92.)

Konkoly examined γ Cass. (and β Lyræ) repeatedly between 1874 and 1883, without seeing bright lines; Gothard repeatedly examined both stars after the autumn of 1881, but saw no trace of bright lines until 1883. ('Astr. Nachr.,' 2581.)

The Greenwich observations for October 1st, and November 21st, 1880, December 7th, 1881, and November 16th, 1883, show the F line bright. No mention is made of bright D_3 or C, but only F was being used to measure velocity in line of sight, and so the others may not have been particularly noted.

Gothard, in 'Astr. Nachr.,' No. 2539, records his observations on August 20th, 1883, when C, F, D_3, and the absorption band at 633 were visible.

Konkoly took up this work at once, and in the O'Gyalla Observations we find two sketches of the spectrum as seen by him. In the first C and F are bright lines sharply defined. D_3 is seen as a bright line, while between D_3 and F is a bright patch of light extending from near 520 to 560. This seems to be absent in the second spectrum, while dark *b* lines and dark D are added as well as bright hydrogen G with a dark line near it.

Sherman at Yale College Observatory records all the bright lines previously observed and many others in addition, but while dark lines are recorded by him, D and *b* are not mentioned.

Gothard ('Astr. Nachr.,' No. 2881) has observed Hα, Hβ, and Hγ as dark lines in β Lyræ, and afterwards as bright lines.

Sherman's observations, in which no mention is made of dark D lines, are of extreme interest, indicating as they do that the sodium line absorption was masked by the bright radiation of manganese, which produces a bright fluting almost exactly in the position of D_3. Gothard, in 'Astr. Nachr.,' No. 2581, records the fact that the dark sodium lines became visible only when D_3 had ceased to be seen as a bright line. Later on in the same paper, however, he records bright D_3 and dark D in β Lyræ, and Konkoly, in

Table of Bright Lines in γ Cassiopeiæ.

Secchi.	Vogel.	Huggins.	Gothard.	Konkoly.	Sherman.	Probable origin.
C.	..	C.	C.	C.	C.	H.
					635·6	(?) Limerick Met.
					616	Fe.
D_3.	D_3.	D_3.	D_3.	D_3.	D_3. }	Mn.
					584 ? }	
					555·75	Mn.
					542·2	Mn.
					530·98	(?) Coronal line.
					516·75	C.
					499	Mg.
F.	F.	F.	F.	F.	F.	H.
					462·3	
				G.	G.	H.
					418	
					h.	H.

Dark Lines.

Secchi.	Vogel.	Huggins.	Gothard.	Konkoly.	Sherman.	Probable origin.
				666·2—656		
			633	659·0—624	628	
			589	589		D.
					576	
			517 (*b*)	516 (*b*)		*b*.
					502	
					492	
				431	467·35	
					399·3	

vol. 6 of the O'Gyalla Observations, records the same in γ Cassiopeiæ. When we consider the great variations in brightness of D_3 in these stars and the great changes in the conditions of the radiating meteorites and their atmospheres, indicated by these changes of brightness, these apparently discordant results are not so difficult to understand. An increase in the number of meteorites containing Mn would cut out all the D absorption and brighten D_3; an increase of sodium and a decrease of Mn would cause the D dark lines to assert themselves, while the condition of bright D_3 and dark D is obtained by increased quantities of Mn and Na vapours produced by collisions.*

Sherman does not record dark *b* lines, although Konkoly observed them several times. Sherman, however, saw the bright carbon at 517, which would completely mask the *b* lines. It seems possible Konkoly saw this bright carbon, and by contrast with the surrounding spectrum, imagined he saw the dark "*b*" lines—at any rate no other observer has recorded dark *b*.

Sherman saw the magnesium 500, while neither Konkoly nor

* Konkoly's D_3 extends quite up to D dark and seems more like a fluting than a bright line.

Gothard noticed it; so after all it may be probable that Konkoly's record of magnesium absorption at *b* was right, and that in Sherman's observation it was masked by the carbon band.

Sherman, in 'Astr. Nachr.,' No. 1707, gives a list of fifteen bright lines in γ Cassiopeiæ, the wave-lengths of which he has determined as accurately as possible. He says, "the difficulties of the observation and the roughness of the recording apparatus have hindered the completely satisfactory identification of the lines. Assuming the position of the hydrogen lines and D_3, and on their basis constructing a curve connecting scale-reading and wave-length, the mean of nine observations upon γ Cassiopeiæ affords the following approximate wave-lengths." (See map.)

The line in the yellow being assumed as D_3 at 5875, instead of the 5870 manganese, causes an error running all through the measurements, but not sufficient to invalidate any conclusions based on the corrected wave-lengths.

The hydrogen lines seen are C, F, hydrogen G, and *h*. We have the manganese at 558 and 586 (D_3), as well as the low-temperature line (bunsen) at 540. Iron is represented by lines at 527, 579, and 616, these being the strongest low-temperature lines. Magnesium is responsible for the 500 line while the carbon accounts for the 517, thus leaving only the 636 and the 463 lines unaccounted for.

The line at 636 has been seen in the Limerick meteorite, although its origin has not yet been determined, while the 463 line is bright in R Geminorum, but has up to the present not been detected in any experiment with meteorites. In the spectrum of the first of Wolf and Rayet's stars in Cygnus (B.D. 35°, No. 4001), Vogel has observed the manganese lines at 540 and 558, the iron lines at 527 and 579, and the hydrogen F, all of which are present in γ Cassiopeiæ, the only additional lines seen in 1st Cygnus being the sodium green, 569, and cadmium, 507.

On the Sequence of Temperature of the Stars in Cygnus.

The three "bright line stars" in Cygnus, discovered by MM. Wolf and Rayet in 1867, present differences in their spectra, which raise some very interesting questions for discussion. Wolf and Rayet did not observe any great differences in the spectra, simply recording the fact that the second star gave the lines most brilliantly; but Dr. Vogel has, in his investigations, brought out very striking ones.

Thus the first of these stars, B.D. + 35°, No. 4001, has seven bright lines in its spectrum, as shown on his light curve, besides the bright band at 468. One of the bright lines is hydrogen F (486). The second, B.D. + 35°, No. 4013, and third, B.D. + 36°, No. 3956, stars have only four bright lines, and the bright band; the hydrogen (F) line being absent.

These differences may at first sight be taken as indicating a higher temperature in the first of these stars than in either of the others, but further investigation seems to indicate this is not the case. The continuous spectrum from the meteorites is very faint in each case, and on it is superposed bright carbon, that in the blue showing itself as a separate bright band, 468. The curve rises in each star at 564 carbon, and is high in the position 517.

It will be seen from the light curves that the rise at 564 is less in 1st Cygnus than in either of the other stars, and the end of the fluting 558, due to the manganese, becomes visible as a line in this star, while in 2nd and 3rd Cygnus the carbon at 564 with this fluting produces such a brightening of the spectrum that the manganese cannot be seen as a bright line. In 2nd Cygnus the 564 carbon is nearly equal in brightness to the 558 manganese fluting, and these produce together such an intensely bright patch between those wave-lengths that we get apparent dark spaces on each side of it. The 540 line of manganese has a considerable difficulty in showing itself on the bright spectrum due to meteorites and carbon combined, whereas in 1st Cygnus where the radiation of carbon is weaker the line is very bright. The invisibility of 507 and 527 in the spectra of 2nd and 3rd Cygnus stars is therefore due probably to the extra brightness of the fluting spectrum due to carbon, rather than to the lower temperature of these stars. The greater number of lines in 1st Cygnus indicates therefore a lower temperature than in the other stars, and this conclusion is borne out by the appearance of the 636 line in 2nd and 3rd Cygnus, and its absence from 1st Cygnus.

The conclusion which has been arrived at after a careful consideration of these stars is that 1st Cygnus is the coolest, 2nd Cygnus ranks next above in temperature, and 3rd Cygnus is the hottest of the three.

With regard to the line in 2nd and 3rd Cygnus at 636 there is an element of doubt as to the true position. Vogel does not give the wave-length in his list of lines, neither does he show it in his sketch of the spectrum, but he indicates its position on the light curve, and from this a curve had to be drawn and the wave-length ascertained as nearly as possible. Vogel suggests the line may be the hydrogen C line, but this seems very improbable, since F is absent, and although F is frequently recorded in bright-line stars without C, in no case is C given without F. It may be the C line is seen clearly because there is no continuous spectrum near it, while F is not visible on account of the bright spectrum around it.

The above stars are not the only ones with bright lines in the constellation Cygnus.

A recent communication by Professor Pickering gives the following additional information :—*

* 'Nature,' September 9, 1886.

A recent photograph of the region in Cygnus, previously known to contain four spectra exhibiting bright lines, has served to bring to our knowledge four other spectra of the same kind. One of these is that of the comparatively bright star P Cygni, in which bright lines, apparently due to hydrogen, are distinctly visible. This phenomenon recalls the circumstances of the outburst of light in the star T Coronæ, especially when the former history of P Cygni is considered. According to Schönfeld, it first attracted attention, as an apparently new star, in 1600, and fluctuated greatly during the seventeenth century, finally becoming a star of the fifth magnitude, and so continuing to the present time. It has recently been repeatedly observed at the Harvard College Observatory with the meridian photometer, and does not appear to be undergoing any variation at present.

Another of the stars shown by the photograph to have bright lines is D.M. + 37° 3821, where the lines are unmistakably evident, and can readily be seen by direct observation with the prism. The star has been overlooked, however, in several previous examinations of the region, which illustrates the value of photography in the detection of objects of this kind.

The other two stars first shown by the photograph to have spectra containing bright lines are relatively inconspicuous. The following list contains the designations according to the 'Durchmusterung,' of all eight stars, the first four being those previously known:—35° 4001, 35° 4013, 36° 3956, 36° 3987, 37° 3821, 38° 4010, 37° 3871, 35° 3952 or 3953. Of these 37° 3171 is P Cygni, and 37° 3821, as above stated, is the star in the spectrum of which the bright lines are most distinct.

[Received March 28, 1888.]

Part IV.—Sub-groups and Species of Group II.

1. General Discussion of Dunér's Observations.

In the paper communicated to the Royal Society last November I pointed out that the so-called "stars" of Class IIIa were not masses of vapour like our sun, but swarms of meteorites; the spectrum being a compound one, due to the radiation of vapour in the interspaces and to the aborption of the light of the red- or white-hot meteorites by vapours volatilised out of them by the heat produced by collisions.

I also showed that the radiation was that of carbon vapour, and that some of the absorption was produced by the chief flutings of Mn and Pb.

These conclusions were arrived at by comparing the wave-lengths of the details of spectra recorded in my former paper with those of

the bands given by Dunér in his admirable observations on these bodies.*

Dunér in his map gives eleven absorption bands, chiefly flutings, in Class III*a*, but in the case of the tenth and eleventh bands there is some discrepancy between his map and the text, to which reference will be made subsequently. His measurements are of the darker portions of the flutings, speaking generally.

It will be clear at once that in the case of the *dark* flutings the dark bands should agree with the true *absorption* of the vapours, and that when the amount of absorption varies, only that wave-length away from the maximum of the flutings will vary. Thus, the same fluting may be represented in the following manner, according to the quantity of the absorbing substance present.

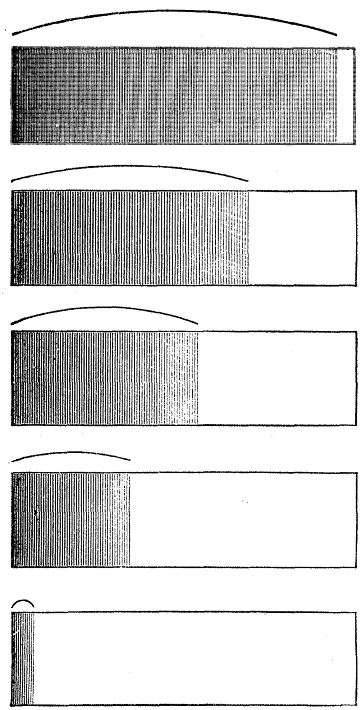

FIG. 12.—Diagram showing how an absorption fluting varies in width according to the quantity of absorbing substance present.

In the case of the *bright* flutings, however, the dark bands on either side may *in some cases* be produced partly by contrast only, and the

* "Les Étoiles à Spectres de la troisième classe."—'Kongl. Svenska Vetenskaps-Akademiens Handlingar,' Band 21, No. 2, 1885.

brighter and wider the bright flutings are the more the dark flutings on either side of them will appear to vary, and in two ways: first, they will dim by contrast when the bright fluting is dimmer than ordinary; and secondly, the one on the side towards which the bright fluting expands from its most decided edge will diminish as the bright fluting expands. See following diagram.

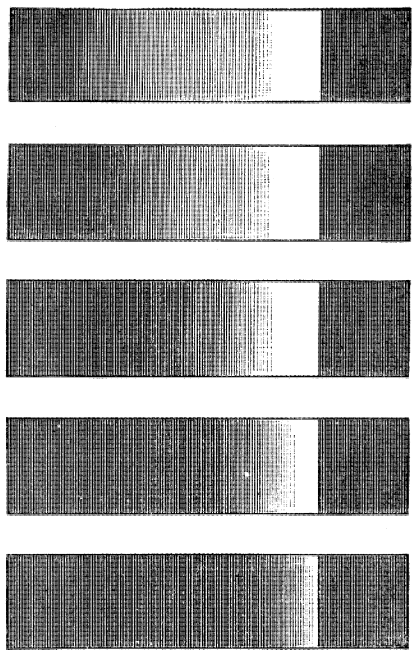

FIG. 13.—Diagram showing the variation in width of a bright fluting and the consequent variation in width of the contrast band at the fainter edge.

There is also another important matter to be borne in mind. As these spectra are in the main produced by the integration of the continuous spectra of the meteorites, the bright flutings of carbon, and the dark flutings produced by the absorption of the continuous spectra by the vapour surrounding each meteorite; the proportion of bright fluting area to dark fluting area will vary with the reduction of the spacing between the meteorites.

If any bright or dark flutings occur in the same region of the spectrum, when the spaces are greatest, the radiation effect will be stronger, and the absorption fluting will be "masked;" where they are least the radiation itself will be masked. This reasoning not only applies to flutings but to lines also.

The Radiation Flutings.

We will first deal with the radiation flutings—those of carbon. The brightest less refrangible edge of the chief one is at wave-length 517, where it sharply cuts off the tail end of the absorption of the magnesium fluting the darkest edge of which begins at 520, as the carbon light from the interspace pales the absorption. The same thing happens at the more refrangible edge of the other absorption of Mg at 500, as Dunér's figures show.

	Less refrangible edge.		More refrangible sharp edge.
Band 8 (absorption of Mg)	502	......	496 in α Herculis.
	501	......	496 in ρ Persei.
	503	......	496 in R Leonis Min.
	505	......	496 in β Pegasi.

If this explanation of the rigidity of the less refrangible edge may be accepted, it is suggested that the rigidity of the end of band 8 at 496, near the nebula line 495, seems to indicate that we may have that line as the bright, less refrangible, boundary of another radiation fluting.

The fluting at 517 is the chief radiation fluting of carbon. The next more refrangible one, which would be most easily seen, as the continuous spectrum would be less bright in the blue, has its less refrangible and brightest edge at 474.

This in all probability has been seen by Dunér, though, as before stated, there is here a discrepancy between his maps and his text. It lies between his dark bands 9 and 10, the measurements of which are as follow:—

	Less refrangible edge.		More refrangible edge.
Band 9	482	......	476 in α Orionis.
	484	......	477 in β Pegasi.
Band 10	472	......	460 in α Orionis.
	474	......	462 in α Herculis.

It is not necessary for me to point out the extreme and special difficulty of observations and determinations of wave-lengths in this part of the spectrum. Taking this into consideration, and bearing in mind that my observations of the chemical elements have shown me no other bands or flutings in this region, I feel justified in looking upon the narrow bright space between bands 9 and 10 as an indication of another carbon fluting—the one we should expect to find associated with the one at 517, with its bright edge at 473 instead of 476, where Dunér's measurements place it. There is a bright fluting in this position in Nova Orionis.

I shall refer to both these points later on.

The third fluting, the carbon one with its brightest edge at 564, is certainly also present; though here the proof depends upon its masking effect, and upon the manner in which this effect ceases when the other flutings narrow and become faint.

In addition to these three flutings of carbon, which we shall distinguish in what follows as carbon A, there is sometimes a fourth more refrangible one beginning at wave-length 461, which is due to some other molecular form of carbon; this we shall distinguish as carbon B. It extends from wave-length 461 to 451, and, as we shall presently see, it is this which gives rise to the apparent absorption band No. 10 in the blue.

It is very probable also that in some cases there is, in addition to carbon A and carbon B, the hydrocarbon fluting which begins at wave-length 431, the evidence of this being Dunér's apparent absorption band 11. It may be remarked here, that although most of the luminosity of this fluting is on the more refrangible side of 431, there is also a considerable amount on the less refrangible side.

With regard to bands 9, 10, and 11, then, there is little doubt that they are merely dark spaces between the bright blue flutings of carbon, and that whether they are seen or not depends upon the relative brightness of the carbon flutings and the continuous spectrum from the incandescent meteorites. When the continuous spectrum is faint, it will not extend far into the blue, and the resulting dark space between the bright carbon A fluting at 474 and the end of the continuous spectrum is the origin of the apparent absorption band 9. When the continuous spectrum gets very bright, band 9 should, and does, disappear. On reference to the maps of the spectra of the "stars" with bright lines, it will be seen that the broad apparent absorption band in the blue agrees exactly in position with band 9, and it undoubtedly has the same origin in both cases. This band may therefore be regarded as the connecting link between the bodies belonging to Group I and those belonging to the group under consideration.

Band 10 is the dark space between the bright carbon A fluting at 474 and the carbon B at 461, and can only exist so long as the carbon flutings are brighter than the continuous spectrum. Dunér's mean values for the band are 461—473, and on comparing these with the wave-lengths of the carbon flutings (see fig. 16) it will be seen that the coincidence is almost perfect.

There is a little uncertainty about band 11, which Duner was only able to measure in one star, but it very probably has its origin in the dark space between the bright carbon B fluting and the hydrocarbon fluting at 431 (see fig. 16). This would give a band somewhat broader and more refrangible than that shown in Dunér's map; but,

as already pointed out, great accuracy in this part of the spectrum cannot be expected.

It may here be mentioned that in the maps which accompany this paper, the compound structure of the hot carbon flutings has been omitted, because the details are not, as a rule, seen in the spectra of heavenly bodies in which there are indications of carbon. The flutings are represented as simple ones beginning at the brightest edge and fading off gradually.

Chemical Substances indicated by the Absorption Flutings and Bands.

I may state that I have now obtained evidence to show that the origin of the following *absorption* flutings is probably as under:—

No. of Fluting.	Origin.	Wave-length of darkest most refrangible edge.	Wave-length of less refrangible end, given by Dunér as measured in α Orionis.
2	Fe	616	628
3	Mn (2)	585	595
4	Mn (1)*	558	564
5	Pb (1)†	544	550
6	Ba‡	524	526
7	Mg	521	517
8	Mg	500	495

These flutings are characteristic of the whole class, and Dunér's catalogue consists chiefly of a statement of their presence or absence, or their varying intensities, in the different stars.

He gives other bands and wide lines which he has measured, specially in α Orionis. I have also discovered the origin of the majority of these. They are as follows:—

			Wave-length.
	I.	Fluting of Cr (1)......................	581
	II.	?	570—577
	III.	Fluting of Pb (2)	567
	IV.	?	543
	V.	Line of Mn seen in bunsen..............	538—540
	VI.	Band of Ba..........................	532—534
Lines	1.	Fluting of Cr (2)......................	559§
	2.	,, ,, (3)......................	536
	3.	Line of Cr seen in bunsen	520

* Means strongest fluting.

† The second Pb band has been seen in α Scorpii and α Orionis. Owing to an error in the map in the former paper, this fluting was ascribed to zinc.

‡ This is the second brightest band, wave-length 525. The first at wave-length 515, is masked by the radiation fluting at 516. See *post*.

§ This is not given by Dunér. It would be masked by the Mn fluting in the star. I have inserted it to show that we could not be dealing with the 3rd fluting of Cr at 536 if we could not explain the apparent absence of the 2nd.

Lines	4.	Ba band	514*
	5.	1st, 2nd, and 3rd Ba flutings	601
	6.		634
	7.		649

Band 1, which extends from wave-length 649·5 to 663·8, has not yet been allocated.

Tests at our Disposal.

In order to prove that my explanation of the nature of these celestial bodies is sufficient, a discussion of the individual observations of them, seeing that differences in the spectra are known to exist, should show that all the differences can be accounted for in the main by differences in the amount of interspace; that is to say, by a difference between the relative areas of space and meteorite in a section of the swarm at right angles to the line of sight. I say in the main, because subsequent inquiry may indicate that we should expect to find minor differences brought about by the beginnings of condensation in large as opposed to small swarms, and also by the actual or apparent magnitudes of the swarms varying their brilliancy, thus enabling a more minute study to be made of the same stage of heat in one swarm than in another.

How minor differences may arise will be at once seen when we consider the conditions of observation.

The apparent point of light generally seen is on my view produced not by a mass of vapour of more or less regular outline and structure, but by a swarm of meteorites perhaps with more than one point of condensation.

An equal amount of light received from the body may be produced by any stage, or number of nuclei, of condensation; and with any differences of area between the more luminous centre and the outliers of the swarm.

All these conditions producing light of very different qualities are integrated in the image on the slit of the spectroscope.

I have said "generally seen," because it has been long known that many of the objects I am now discussing are variable, as well as red, and that at the minimum they are not always seen as sharp points of light† but have been described as hazy.

The severe nature of the tests at our disposal will be recognised when we inquire what must follow from the variation of the spacing. Thus, as the spacing is reduced—

I. The temperature must increase.

* In the early stages this band is masked by the vivid light coming from the carbon in the interspaces.

† Hind first noticed this in 1851. Quoted by Arago, 'Astronomie Populaire.'

α. Vapours produced at the lowest temperatures will be the first to appear.

β. The spectrum of each substance must vary with the quantity of vapour produced as the temperature increases, and the new absorptions produced must be the same *and must follow in the same order* as those observed in laboratory experiments.

II. The carbon spectrum must first get more intense and then diminish afterwards as the spaces, now smaller, are occupied by vapours of other substances.

α. The longest spectrum will be that produced by mean spacing.

β. The masking of the dark bands by the bright ones must vary, and must be reduced as the mean spacing is reduced.

III. The continuous spectrum of the meteorites must increase.

α. There will be a gradually increasing dimming of the absorption bands from this cause.

β. This dimming will be entirely independent of the width of the band.

IV. The spectrum must gradually get richer in absorption bands.

α. Those produced at the lowest temperatures will be relatively widest first.

β. Those produced at the highest temperatures will be relatively widest last.

γ. They must all finally thin.

These necessary conditions, then, having to be fulfilled, I now proceed to discuss M. Dunér's individual observations. I shall show subsequently that there are, in all probability, other bodies besides those he has observed which really belong to this group.

II. Discussion of Dunér's Individual Observations.

Consideration of the Extreme Conditions of Spacing.

Cœteris paribus, when the interspaces are largest we should have a *preponderance* of the radiation of carbon, so far as quantity goes. The bands will be wide and pale, the complete radiation will not yet be developed; a minimum of metallic absorption phenomena—that is, only the flutings of magnesium (8 and 7), the first fluting of manganese (3), and the first fluting of iron (2); but the great width of the bright band at 517 will mask band 8.

When the interspaces are least, the radiation of carbon should give place to the absorption phenomena due to the presence of those metallic vapours produced at the highest temperature at which a swarm can exist as such; the bright flutings of carbon should be

diminished, and the true absorption flutings of Mg, Fe, Mn, Pb, and the band of Ba, should be enhanced in intensity.

There will be an *inversion* between the radiation and absorption.

The highest intensity of the absorption phenomena will be indicated by the strengthening of the bands 2, 3, 4, 5, and 6, and the appearance of the other flutings and bands specially recorded in α Orionis. The bands 7 and 8 will disappear as they are special to a low temperature, and will give way to the absorption of manganese, iron, *b*, &c.

This inversion, to deal with it in its broadest aspect, should give us at the beginning 7 strong, and 2, 3 weak, and at the end 7 and 8 weak, and 2, 3 strong.

The first stage, representing almost a cometic condition of the swarm before condensation has begun, has been observed in Nos. 3,* 23, 24, 25, 36, 68, 72, 81, 118, 247, 249. There is a very large number of similar instances to be found in the observations. The above are only given as examples.

The *last* stage, before all the bands fade away entirely, has been observed in Nos. 1, 2, 26, 32, 33, 38, 40, 61, 64, 69, 71, 75, 77, 82, 96, 101, 116. As before, these are only given as instances.

It is natural that these extreme points along the line of evolution represented in the bodies under consideration should form, as I think they do, the two most contrasted distinctions recorded by Dunér—that is, recorded in the greatest number of cases.

Origin of the Discontinuous Spectrum.

I have already shown that when the meteorites are wide apart, though not at their widest, and there is no very marked condensation, the spectrum will extend farther into the blue, and therefore the flutings in the blue will be quite bright; in fact, under this condition the chief light in this part of the spectrum, almost indeed the only light, will come from the bright carbon. Under this same condition the temperature of the meteorites will not be very high, there will therefore be little continuous spectrum to be absorbed in the red and yellow. Hence we shall have discontinuity from one end of the spectrum to the other. This has also been recorded, and in fact it is the condition which gives us almost the most beautiful examples of the class (196, α Herculis, 141, 172, 229).

The *defect* of continuous light *in the blue* in this class, after condensation has commenced, and the carbon flutings are beginning to disappear, arises from defect of radiation of the meteorites, and hence in all fully-developed swarms the spectrum is not seen far into the blue for the reason that the vapours round each meteorite are at a temperature such that fluting absorption mainly takes place, although

* The references are to the numbers of the stars in Dunér's catalogue.

of course there must be some continuous absorption in the blue. This is perhaps the most highly-developed normal spectrum-giving condition; 44, 45, 55, 60, 65, 86, 92, 278 are examples.

The Paling of the Flutings.

Subsequently, the spectra are in all cases far from being discontinuous, and the flutings, instead of being black, are pale. Thus, while the bands are dark in the stars we have named, they are not so dark in α Orionis. Here, in short, we have a great distinction between this star and α Herculis, o Ceti, R Lyræ, and ρ Persei.

Obviously this arises from the fact that the average distances between the meteorites have been reduced; their temperature being thereby increased as more collisions are possible, the vapours are nearly as brilliant as the meteorites, and radiation from the interspaces cloaks the evidences of absorption. Nor is this all: as the meteorites are nearer together, the area producing the bright flutings of the carbon is relatively reduced, and the bands 10 and 9 will fade for lack of contrast, while 8 and 7 will fade owing to the increased temperature of the system generally carrying the magnesium absorption into the line stage; *b* is now predominant (see 102, 157, 163, 114, 125, 135).

Under these conditions the *outer* absorbing metallic atmosphere round each meteorite will in all probability consist of Mn and Fe vapours, and in this condition the masking effect will least apply to them. This is so (114, 116); they remain dark, while the others are pale.

Here we have the indication of one of the penultimate stages already referred to.

Phenomena of Condensation.

Dealing specially with the question of condensation,—I have already referred to possibly the first condition of all, recorded by Dunér in the observations now discussed—I may say that the first real and obvious approach to it perhaps is observed when all, or nearly all, except 9 and 10 of the flutings are *wide* and *dark*. The reasons will be obvious from what has been previously stated. Still more condensation will give all, or nearly all, the bands wide and pale, while the final stage of condensation of the swarm will be reached when all the bands fade and give place to lines. We have then reached Class II (107, 139, 168, 264); 2 and 3 should be and are perhaps the last to go (203).

The Bands 9 and 10.

With regard specially to the bands 9 and 10, which include between them a bright space which I contend is the second fluting of carbon, I may add that if this view is sound, the absence of 10 should mean a broad carbon band, and this is the condition of non-condensation, though not the initial condition. The red flutings should therefore be well marked—whether broad or not does not matter; but they should be dark and not *pale*. Similarly the absence of band 9 means non-condensation.

Therefore 9 and 10 should vary together, and as a matter of fact we find that their complete absence from the spectrum, while the metallic absorption is strong, is a very common condition (1, 2, 6, 16, 26, 32, 39, 40, 46, 54, 60).

That this explanation is probably the true one is shown by further consideration of what should happen to the red flutings when 9 and 10 are present. As the strong red flutings indicate condensation, according to my view this condensation (see *ante*) should pale the other flutings. This happens (3, 8, 13, 28, 35, 45, 30; and last, not least, among the examples, I give 50, α Orionis).

III. Results of the Discussion.

The Line of Evolution.

I have gone over all the individual observations recorded by Dunér, and, dealing with them all to the best of my ability in the light afforded by the allocation of the bands to the various chemical substances, the history of the swarms he has observed seems to be as follows :—

(1) The swarm has arrived at the stage at which, owing to the gradual nearing of the meteorites, the hydrogen lines, which appeared at first in consequence of the great tenuity of the gases in the interspaces, give way to carbon. At first the fluting at 473 appears (as in many bright-line stars), and afterwards the one at 517. This is very nearly, but, as I shall show subsequently, not quite, the real beginning of the group, and the radiation is now accompanied by the fluting absorption of Mg, Fe, and Mn—bands 7, 2, 3. This is the absorption produced at the temperature of the oxy-coal-gas flame, while the stars above referred to give us the bright line of Mn seen at the temperature of the bunsen.

(2) The bright band of carbon at 517 narrows and unveils the Mg absorption at band 8. We have 8 now as well as 7 (both representing Mg), added to the bands 2 and 3, representing Fe and Mn, and these latter now intensify.

(3) The spacing gets smaller; the carbon, though reduced in

relative quantity, gets more intense. The second band at 473 in the blue gets brighter as well as the one at 517. We have now bands 9 and 10 added. This reduced spacing increases the number of collisions, so that Pb and Ba are added to Mg, Fe, and Mn. We have the bands 2, 3, 4, 5, 6, 7, 8, 9, and 10. This is the condition which gives, so to speak, the normal spectrum.

(4) This increased action will give us a bright atmosphere round each meteorite, only the light of the meteorite in the line of sight will be absorbed: we shall now have much continuous spectrum from the interspaces as well as the vapour of carbon. *The absorption flutings will pale*, and the Mg flutings will disappear on account of the higher temperature, while new ones will make their appearance.

(5) Greater nearness still will be followed by the further dimming of the bright carbon flutings including the one at 517. The blue end of the spectrum will shorten as the bands fade, narrow, and increase in number. If the star be bright, it will now put on the appearance of α Orionis; if dim, only the flutings of Fe and Mn (1), bands 2 and 3, will remain prominent.

(6) All the flutings and bands gradually thin, fade, and disappear. A star of the third group is the result.

In the latter higher-temperature stages we must expect hydrogen to be present, but it need not necessarily be visible, as the bright lines from the interspaces may cancel or mask the absorption in the line of sight of the light of the meteorites; but in case of any violent action, such as that produced by another swarm moving with great velocity, we must expect to see them bright, and they are shown bright in a magnificent photograph of *o* Ceti, taken for the Draper Memorial, which I owe to the kindness of Professor Pickering. I shall return to this question.

Stages antecedent to those recorded by Dunér.

So far I have referred to the swarms observed by Dunér. The result of the discussion has been to show that all the phenomena are included in the hypothesis that the final stages we have considered are antecedent to the formation of stars of Group III, bodies which give an almost exclusively line absorption, though these bodies are probably not yet stars, if we use the term star to express complete volatilisation, similar to that observed in the case of our sun.

The question then arises, Are all the mixed fluting stages really included among the objects already considered?

It will be remembered that in my former communication I adduced evidence to the effect that the mixed fluting stage was preceded by others in which the swarms were still more dispersed, and at a lower temperature. The first condition gives us bright hydrogen; the last little continuous spectrum to be absorbed, so that the spectrum is one

with more bright lines than indications of absorption; and, in fact, the chief difference between the spectra of these swarms and of those still sparser ones which we call nebulæ lies in the fact that there are a few more bright metallic lines or remnants of flutings; those of magnesium, in the one case, being replaced by others of manganese and iron.

If my view be correct—if there are stages preceding those recorded by Dunér in which we get both dark and bright flutings—it is among bodies with spectra very similar to these that they should be found.

The first stage exhibited in the objects observed by Dunér is marked by flutings 7, 3, and 2 (omitting the less refrangible one not yet allocated), representing the flutings Mg, Mn, and Fe visible at the lowest temperatures.

The stars which I look upon as representing a prior stage should have recorded in their spectra the flutings 7 and 3 (without 2), representing Mg and Mn.

Classification into Species.

We are now in a position to apply all that has gone before in summarised statements of the various spectral changes, including those connected with hydrogen, which take place not only in these objects studied by Dunér, but in those others to which I have referred as forming the true beginning of the group.

The following statements and tables, however, must not be taken as anything else than a first approximation to the real criteria of specific differences. I am convinced that further thought is required on them, and that such further thought will be well repaid.

The Sequence of the Various Bands in the Spectra of the Elements indicated by Bodies of the Group.

In comparing the spectrum of an element which has been mapped in the laboratory with the absorption bands in the spectrum of a "star," we need only consider those bands and flutings which stand out prominently and are the first to flash out when there is only a small quantity present. Thus, in the flame spectrum of barium there is an almost continuous background of flutings with a few brighter bands in the green, and it is only important to consider the *bands*, as the flutings would mainly produce a general dimming of the continuous spectrum. In order to show at a glance what portions of the spectrum of an element it is most important for us to consider in this discussion, I have reconstructed the map of low-temperature spectra which I gave in my previous paper, with reference to those elements which are indicated in the spectra of bodies of Group II. Five orders of intensities are represented, the longest lines, flutings, or bands

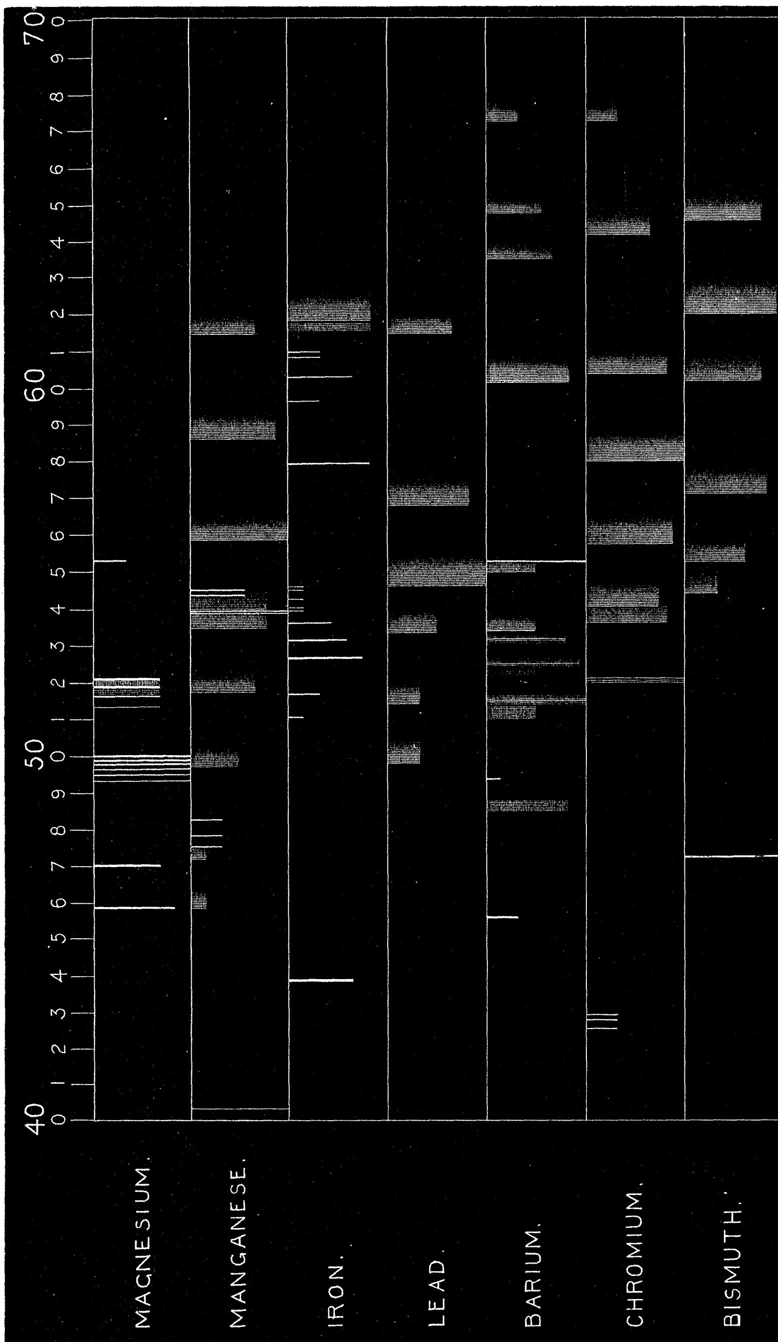

FIG. 14.—Map showing the lines, bands, and flutings seen in the spectra of the elements which are indicated in bodies of Group II.

being the brightest (fig. 14). The lines, flutings, or bands in the lowest horizon, in the case of each element, are those seen at the lowest temperatures, and are the first to appear when only a small quantity of substance is present. Those in the upper horizons are the faintest, and are only seen when the temperature is increased, or a considerable amount of the substance is volatilised. The map shows that if there are any indications of magnesium, for instance, in bodies at low temperatures, the fluting at 500 will be seen, possibly without the other fluting or lines. The first indications of manganese will be the fluting at 558, and so on. Again, on account of the masking effect of the spectrum of one element upon that of another, we may sometimes have an element indicated in a star spectrum, not by the brightest band or fluting in its spectrum, but by the second or even third in brightness; this, of course, only occurs when the darkest band falls on one of the brightest flutings of carbon, or upon a dark band in the spectrum of some other element. In the former case the dark band will be cancelled or masked; in the latter case the two absorptions will be added together, and form a darker band of a different shape.

The Question of Masking.

If we consider the masking effects of the bright carbon flutings upon the absorption spectrum of each of the elements which, according to the results obtained, enter into the formation of Dunér's bands, we have the following as the main results:—

Magnesium.—There are two flutings of magnesium to be considered, the brightest at 500 and the other at 521. In the earlier stages of Dunér's stars only the fainter one at 521 is visible, but the absence of the brightest at 500 is accounted for by the masking effect of the bright carbon fluting starting at 517. As the carbon fades, the 517 fluting narrows and the absorption of magnesium 500 becomes evident.

Manganese.—The two chief flutings of manganese are at 558 and 586, the former being the brightest fluting in the spectrum. The *second* fluting is seen in all [of Dunér's stars. The first fluting, 558, however, does not appear as an absorption fluting until the radiation fluting of carbon starting at 564 has narrowed sufficiently to unmask it. It is thus easy to understand why, in some stars, there should be the second fluting of manganese without the first.

Barium.—The spectrum of barium consists of a set of flutings extending the whole length of the spectrum, and standing out on this as a background are three bright bands; the brightest band is at 515, the second is at 525, and the third, a broader band, is about 485. The *second* band is recorded as an absorption band in Dunér's stars, the apparent absence of the *first* band being due to the masking

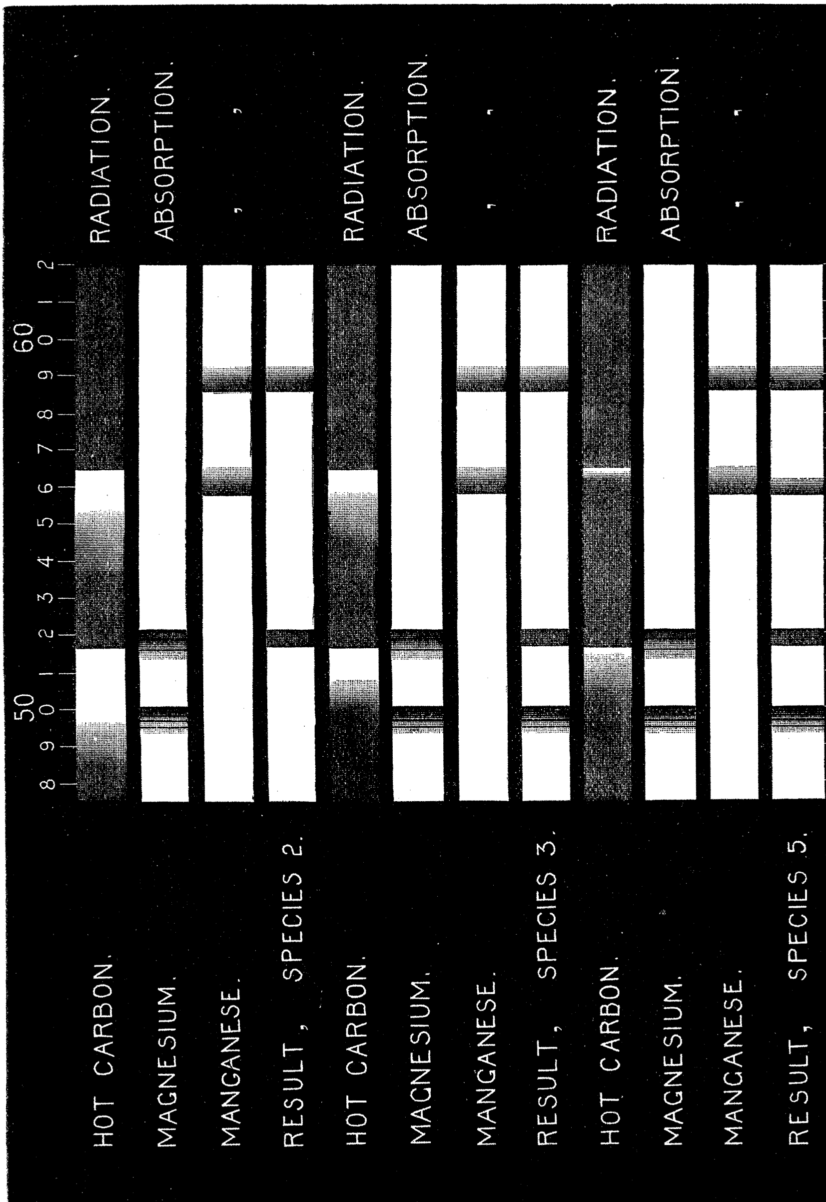

FIG. 15.—Diagram showing the effects of variations in width of the flutings of carbon upon the integrated spectra of carbon radiation and magnesium and manganese absorption, as they appear in different species of bodies of Group II.

effect of the bright carbon at 517. The third band at 485 probably forms a portion of band 9. A fourth band, at 533, and the three brightest flutings at 602, 635, and 648 are also seen in α Orionis.

Chromium.—The flutings of chromium do not form portions of the ten principal bands of Dunér, but the brightest are seen in α Orionis. The brightest fluting is at 580, and this forms band 1; the second, at 557, is masked by the manganese fluting at 558, and the third at 536 is seen as line 2. The chromium triplet about 520, which is visible in the bunsen, is seen as line 3.

Bismuth.—The brightest fluting of bismuth is at 620, the second is at 571, the third at 602, and the fourth is at 646. The first is masked by the iron fluting at 615, the second is seen in α Orionis as band 2 (570—577).

The points I consider as most firmly established are the masking effects of the bright carbon flutings and the possibility of the demonstration of the existence of some of the flutings in the spectrum by this means, if there were no other. There are two chief cases, the masking of the "nebula" fluting 500 by the bright carbon fluting with its brightest less refrangible edge at 517, and that of the strongest fluting of Mn = Mn (1) 558, by the other carbon fluting with its brightest edge at 564. I have little doubt that in some quarters my anxiety not to be content to refer to the second fluting of Mn without being able to explain the absence of the first one, will be considered thrown away, as it is so easy to ascribe any non-understood and therefore "abnormal" spectrum to unknown physical laws; but when a special research had shown me that at all temperatures at which the flutings of manganese are seen at all, the one at 558 retained its supremacy, I felt myself quite justified in ascribing its absence in species 1—4 to the cause I have assigned, the more especially as the Mg fluting which is visible even in the nebula followed suit.

The Characteristics of the Various Species.

I append the following remarks and references to the number of the bodies in Dunér's catalogue, in which the specific differences come out most strongly, to the tabular statement. I also refer to some difficulties.

Sp. 1. The characteristic here is the almost cometary condition. All three bright carbon flutings generally seen in comets are visible; 474 standing out beyond the end of the dull blue continuous spectrum of the meteorites, 516 masking Mg 500, and 564 masking Mn(1) 558. The bands visible in the spectra of bodies belonging to this species will therefore be Mn(2) 586, and Mg(2) 521; band 9 will be so wide and pale that it would most likely escape detection. It is very doubtful whether any of the bodies the spectra of which have hitherto been recorded can be classed in this species, but laboratory

work assuredly points to their existence; it will therefore be extremely interesting if future observations result in their discovery. It is possible, however, that No. 150 of Dunér's list belongs to this species, but the details are insufficient to say with certainty. His description is as follows:—"150. Il me paraît y avoir une bande étroite dans le rouge, et une plus large dans le vert" (p. 55).

Sp. 2. Characteristics: appearance of Fe. The number of bands now visible is three—namely, 2, 3, and 7. The iron comes out as a result of the increased temperature. Mg(1) and Mn(1) are still masked by the bright carbon flutings, and there is still insufficient luminosity to make the apparent absorption-band 9 dark enough to be noticed.

Sp. 3. Characteristics: appearance of Mg 500, which has previously been masked by the carbon bright flutings 517. 7 and 8 are now the darkest band in the spectrum.

Sp. 4. Characteristics: appearance of Pb(1) 546, *i.e.*, band 5. This, if present in the earlier species at all, would be masked by the bright carbon at 564.

Sp. 5. Characteristics: Mn(1) is now unmasked. The bands now visible are 2, 3, 4, 5, 7, and 8, the two latter still being the widest and darkest, because they are essentially low-temperature phenomena.

Sp. 6. Characteristics: band 6, *i.e.*, Ba(2), 525, is now added. The first band of Ba at 515 is masked by the bright carbon at 517. The bands now visible are 2—8, 7 and 8 still being widest and darkest. They will all be pretty wide, and they will be dark because the continuous spectrum will be feebly developed.

Sp. 7. Characteristics: appearance of band 9. This, which has been already specially referred to, has been too wide and pale to be observed in the earlier species. Its present appearance is due to the narrowing and brightening of the carbon at 474 and the brightening of the continuous spectrum, the result being a greater contrast. Bands 7 and 8 still retain their supremacy, but all the bands will be moderately wide and dark.

Sp. 8. Characteristics: all the bands 2—9 are more prominent, so that 7 and 8 have almost lost their supremacy.

Sp. 9. Characteristics: appearance of band 1, the origin of which has not yet been determined. All the bands are well seen, and are moderately wide and dark.

Sp. 10. Characteristics: appearance of band 10, and in some cases 11. These become visible on account of the brightening of the carbon B fluting and the hydrocarbon fluting at 431. The spectrum is now at its greatest beauty, and is discontinuous.

Sp. 11. Characteristics: the bands are now becoming wider, and 2 and 3 are gaining in supremacy; 7 and 8 become narrower on

account of the increased temperature. 1 and 10 are only occasionally seen in this species.

Sp. 12. Characteristics: with the expansion of the continuous spectrum towards the blue, band 9 becomes very narrow, and cannot be observed with certainty. The other bands, with the exception of 7 and 8, are becoming wider and paler, while 2 and 3 still gain in supremacy.

Sp. 13. Characteristics: 9 has now entirely disappeared, 2 and 3 still retaining their supremacy.

Sp. 14. Characteristics: all the bands are pale and narrow; 2 and 3 will still be darkest, but the difference will not be so great as in the species preceding.

Sp. 15. Characteristics: in ordinary members of this group, 2 and 3 now alone remain visible: they are wide, but feeble, as the continuous spectrum which has been rapidly developing during the last changes is now strong.

Table A.—Specific Differences in Group II.

Species.	Radiation flutings of carbon.					Absorption flutings. Dunér's bands.		
	Hydro-carbon, 431.	Carbon B, 461.	Carbon A.			10.	9.	8.
			474.	517.	564.			Mg.
1			Very wide and pale	Wide and pale	Wide and pale			If present, masked by 517
2			,,	,,	,,			,,
3			Narrowing and brightening	Narrowing and brightening	Narrowing and brightening			Appears dark
4			,,	,,	,,			Widens
5			,,	,,	Very narrow			,,
6			,,	Brighter and narrower	,,			Still darker and wider
7			,,	,,	,,		Appears	,,
8	Very narrow	Very narrow	,,	,,	,,		Darkens	Narrows
9	Widens	Widens	,,	,,	,,		Strong	,,
10	,,	,,	Fading	Fading	,,	Appears	,,	,,
11	Narrows	Narrows	,,	,,	,,	Narrow in all but the brightest stars	Pales	Pales
12	Gone	,,	,,	Almost gone	,,	Disappears	Almost gone	,,
13		Gone	,,	,,	,,		Gone	,,
14			Gone	,,				,,
15			..	(?) Gone	Gone			Gone

Table A.—Specific Differences in Group II.

Absorption flutings—*cont.*							
7.	6.	5.	4.	3.	2.	1.	Whether hydrogen lines.
Mg.	Ba.	Pb(1).	Mn(1).	Mn(2).	Fe.		
Thin and dark			Present, but masked by 564	Thin and pale	Absent		Yes
”			”	”	Appears thin and pale		No
”			”	”	”		No
Darkens		Appears dark	”	”	”		No
”		• •	Unmasked, dark	Darkens	Darkens		No
Widens	Appears	Appears dark	• •	• •	• •		No
”	Darkens	Widens	Widens	Widens	Widens		No
Narrows	”	”	”	”	”		No
”	”	”	”	”	”	Appears	Yes, bright and variable (possibly dark in α Orionis)
”	• •	• •	”	”	”	Still present	
Pales	Darkens	Pales	Pales	Now very broad and faint	Now very broad and faint	Fading	?
”	Pales	”	”	Pales	Pales	Gone	No
”	”	”	”	Wide and faint	Wide and faint		No
Thin and faint	Thin and faint	Thin and faint	Thin and faint	Narrows	Narrows		No
Gone	Gone	Gone	Gone	”	”		No

Table B.—Showing the Stars in Dunér's Catalogue arranged in Species.

Species 1.

No. of star.	Bands visible.
(150)	Narrow band in the red and a wider one in the green.

Species 2.

No. of star.	Bands visible.
(56)	2, 3, 7.
(93)	2, 3, 7; perhaps 4 and 5.
(220)	2, 3, 7.
(233)	2, 3, 7.
(246)	2, 3, 7; possibly 4 and 5. Feebly developed.

Species 3.

No. of star.	Bands visible.
(42)	Bands weak; 2, 3, 7, 8 best visible.
(53)	2, 3, 7, 8.
(70)	2, 3, 7, 8; weak.
(185)	2, 3, 7, 8.
(198)	2, 3, 7, 8; narrow.
(228)	2, 3; weak. 7 and 8 are well seen.
(276)	2, 3, 7, 8; not very strong.
(290)	2, 3, 7, 8.

Species 4.

No. of star.	Bands visible.
(7)	2, 3, 5, 7, 8.
(95)	2, 3, 7, 8; possibly also 4 and 5.
(110)	2, 3, 7, 8; narrow; 4 and 5 suspected.

Species 5.

No. of star.	Bands visible.
(89)	2, 3, 7, 8; 4 and 5 very weak.
(153)	2, 3, and 7 wide; 4, 5, 8 pale.
(154)	2, 3, 7, 8 narrow; 4 and 5 very narrow.
(173)	Feebly developed; the six ordinary bands feebly visible.
(253)	The six ordinary bands are plainly seen.
(258)	The six ordinary bands, but not very strong.
(267)	2, 3, 7 well marked; 4, 5, 8 pale.
(271)	The six ordinary bands, feebly developed.

Species 6.

No. of star.	Bands visible.
(6)	2—8; wide and dark.
(19)	2—8; 4 and 5 rather weak.
(39)	2—8; strong and wide.
(48)	2—8; well marked.
(67)	2—8; wide and dark.
(74)	2—8; wide and dark.
(76)	2—8; well marked.
(83)	2—8; wide and dark.
(99)	2—8; well seen but not very strongly marked.
(188)	2—8; wide and dark.
(189)	2—8; wide and dark.
(194)	2—8; wide but not very dark.
(202)	2—8; wide and dark in the red and green-blue.
(208)	2—8; well developed, especially in the blue-green.
(214)	2—8; wide and dark.
(227)	2—8; dark but narrow.
(247)	Bands plainly seen, but they are very pale, except 7 and 8.
(254)	2—8; wide and dark.
(259)	2—8; wide and dark, 7 and 8 strongest.
(260)	2—8; dark, but not very wide.
(273)	2—8; dark, but rather narrow.
(274)	There are seven bands, wide and rather dark. (I assume these to be 2—8.)
(285)	2—8; well seen, not remarkably wide.
(289)	2—8; very distinctly visible; 4 and 5 weak and narrow.

Species 7.

No. of star.	Bands visible.
(24)	2—9 ; pretty wide and dark, especially 7 and 8.
(97)	2—9 ; *very dark*, rather narrow.
(115)	2—9 ; wide, especially in the blue.
(143)	2—9 ; wide and dark, especially in green-blue.
(181)	2—9 ; very wide and dark, especially 7 and 8.
(195)	2—9 ; 7 and 8 especially strong.
(229)	2—9 ; very wide, but rather pale ; 7 and 8 very wide and dark.
(241)	2—9 ; well seen. Those in green-blue wide and strong.
(249)	7, 8, 9 are very wide and dark, others very narrow.
(252)	2—10 ; wide and dark, especially in the blue.
(256)	2—10 are seen.
(269)	2—9 ; very dark, but not very wide.
(270)	2—9 ; wide and dark, especially those in the blue.
(275)	2—9 ; wide and dark, especially in the blue.
(284)	2—9 ; wide and dark, especially in the green-blue.

Species 8.

No. of star.	Bands visible.
(15)	2—9 ; strongly developed, wide and dark.
(29)	2—9 ; wide and dark.
(57)	2—10 ; wide and dark.
(88)	2—9 ; wide and strong.
(103)	2—9 ; wide and dark.
(108)	2—9 ; well marked.
(112)	2—9 ; wide, dark.
(137)	2—9 ; wide and dark.
(161)	1—9 ; wide and dark throughout the spectrum.
(166)	2—9 ; wide and dark, 4 and 5 darker than usual.
(184)	2—9 ; wide and black, 6 rather weak.
(225)	2—9 ; well seen throughout the spectrum.
(230)	2—9 ; wide and rather dark.
(242)	2—9 seen ; *strong* and wide.
(251)	2—9 ; wide and dark.
(263)	2—9 ; wide and dark.
(278)	2—9 ; wide and dark.
(283)	2—9 ; wide and dark.
(286)	2—9 ; wide and dark.
(291)	2—9 ; wide and strong.
(295)	2—9 ; wide and dark, but spectrum is not very remarkable.
(297)	2—9 ; well marked, wide and dark.

Species 9.

No. of star.	Bands visible.
(9)	Bands wide and dark.
(12)	Bands wide and dark.
(20)	Bands wide and dark.
(23)	Bands very wide; those in the green-blue are dark.
(25)	1—9; 7 and 8 darker than 2 and 3.
(37)	Some of the bands very wide; 7 and 8 strongest.
(44)	1—9; very fine.
(65)	1—9; wide and dark.
(66)	1—9; very wide and dark; 6 well seen.
(118)	Bands wide and dark, especially in green-blue.
(123)	Bands wide and dark; full spectrum.
(148)	Bands wide and dark, even in the blue.
(156)	Band well marked and very wide throughout the whole spectrum.
(158)	Bands wide and dark; even in the blue.
(162)	1—9; wide and dark.
(174)	Bands wide and dark.
(175)	Bands wide and dark.
(176)	Bands visible, even in the blue; not very dark.
(183)	1—9; wide and dark. A narrow band between 3 and 4.
(186)	Bands well developed, even beyond the blue, but weak in red.
(204)	Bands wide and dark, even in the blue.
(216)	Bands wide and dark.
(217)	1—9, including 6, are very wide and dark.
(221)	Bands wide and dark throughout the spectrum.
(237)	2, 3, 7, 8 are strong; 1, 4, 5 well seen (6 and 9 are also most likely there).
(255)	Bands very dark and of extraordinary width.
(266)	1—9; wide and dark.
(277)	1—9; wide and dark. 4 and 5 wider than usual.
(281)	1—9; wide and dark.
(293)	Bands wide and dark throughout the spectrum.

Species 10.

No. of star.	Bands visible.
(4) (R Andromedæ)	Variable.
(18)	1—11 inclusive.
(28)	Bands rather pale; like that of α Orionis.
(30)	Bands wide, both in green-blue and red.
(86)	1—10; very wide and dark.
(91)	Bands very wide and dark, even in the blue.
(92)	1—10; very wide and dark.
(131)	1—10; 2 and 3 wide, others relatively narrow.
(141)	1—10; very wide and dark.
(172)	2—10, possibly 1; wide and dark.
(196)	1—10; very wide and black.
(232)	1—10.
(239)	1—10; very fine.

Species 11.

No. of star.	Bands visible.
(5)	2—9; 3 is very wide.
(55)	2—9; fine.
(87)	2—9; wide and dark, especially 2 and 3.
(98)	2—9; wide and visible, even in the blue; rather pale.
(135)	1—9; wide and pale.
(149)	1—9; wide and very *dark*. Bands in the red fine.
(152)	1—9; well marked, fine in the red.
(171)	2—9; 2 and 3 strongest.
(177)	2—9; strong and wide, especially in the red.
(191)	2—9; wide and dark, especially 2 and 3.
(193)	2—9; 2 and 3 strongly marked.
(197)	2—9; wide.
(199)	2—9; very wide and *dark*, especially in the red. 4 and 5 are also wider than usual.
(212)	2—9; wide and dark. 2 and 3 are the strongest.
(218)	Bands wide, but not very dark, as far as 9.
(234)	2—9; wide.
(245)	Bands wide, but pale. Strongest in the red.
(288)	Bands wide and pale, but visible even in the blue.

Species 12.

No. of star.	Bands visible.
(27)	2—8; wide and pale.
(46)	2—8, possibly 9.
(51)	2—8, possibly 9.
(52)	2—8, possibly also 9; wide, but not very dark.
(60)	2—8, possibly 9; wide and dark.
(78)	Bands visible even in the blue; wide but pale.
(117)	2—8; feebly developed.
(122)	2—8; wide, but rather pale.
(126)	2—8, possibly 9; 2 and 3 strong.
(129)	2—8; wide and pale.
(133)	Bands wide and dark, especially in the red.
(164)	2—8, probably also 9; red bands darkest.
(215)	2—8; not very strong.
(264)	2—8, possibly 9; wide, but not very dark.

Species 13.

No. of star.	Bands visible.
(1)	2—8; red bands strongest.
(2)	2—8; 2 and 3 strongest.
(16)	2 and 3, pretty strong; 4—8, wide and pale.
(17)	2—8; 2 and 3 strongest.
(26)	2—8; 2 and 3 strongest.
(32)	2—8; 2 and 3 strongest.
(33)	2—8; 2 and 3 strongest.
(36)	2—8; 2 and 3 terminated by strong lines. *b* present.
(38)	2—8; 2 and 3 strongest.
(40)	2—8; 2 and 3 strongest.
(54)	2—8; 2 and 3 strongest.
(61)	2—8; 2 and 3 strongest.
(62)	Red bands fairly strong; 7 and 8 weak; 4 and 5 narrow.
(64)	2—8; 2 and 3 strong.
(69)	2—8; 2 and 3 very dark.
(71)	2—8; 2 and 3 strong.
(75)	2—8; wide and dark, especially in the red.
(82)	2—8; all strong, but especially 2 and 3.
(104)	2 and 3 strong and wide, 7 and 8 fairly strong, 4 and 5 weak.
(109)	2—8; wide and dark, especially in the red.
(116)	2—8; very pale, except 2 and 3.
(120)	2—8; well seen, 2 and 3 widest.
(121)	2—8; 2, 3, 7 strongest.
(124)	2—8; 2 and 3 especially wide and dark.
(130)	2—8; well seen, 2 and 3 strong.
(132)	2—8; narrow, except 2 and 3.
(144)	2—8; well seen, 2 and 3 strongest.
(145)	2—8; well seen, 2 and 3 strongest.
(146)	2—8; rather narrow, 2 and 3 widest.
(155)	2—8; 2 and 3 strong, but not very wide.
(160)	2, 3, 4, 5, 7, 8; 2 and 3 wide and dark.
(182)	2—8; 2 and 3 strongest.
(200)	2—8; well seen, 2 and 3 are the strongest.
(203)	2—8; seen with difficulty, 2 and 3 strongest.
(205)	2—8 are visible, 2 and 3 darkest.
(207)	2—8; 2 and 3 strongest.
(211)	2—8; red strongest.
(240)	The six ordinary bands are strong, but only those in the red are wide.
(243)	The six ordinary bands; wide and dark in the red; 4 and 5 narrow.
(244)	2 and 3; rather wide. Also 7 and 8 seen (not well marked).
(268)	2 and 3 wide and dark; 7 and 8 rather narrow; 4 and 5 not easily seen.
(280)	Six bands, strongest in the red.
(287)	2 and 3 wide and strongly marked; the others not so strong.
(292)	The six ordinary bands are visible, widest in the red.
(294)	2—8; 2, 3 strong, the others narrow.

Species 14.

No. of star.	Bands visible.
(22)	2—8 are seen, but they are not well marked.
(49)	2—8 ; narrow and not very dark.
(90)	2—8 ; narrow and not very dark.
(94)	2—8 ; not strongly marked ; 4 and 5 weak.
(107)	2—8 ; very narrow.
(111)*	2—9 ; narrow.
(113)	2—8 ; feebly developed.
(138)	2—8 ; not strongly marked. 4 and 5 are very narrow.
(140)	2, 3, 5, 7, 8 ; pale and narrow, feebly developed.
(142)	2—8 ; not very wide.
(167)	2—8 ; narrow and not very dark.
(169)	2—8 ; narrow.
(179)	2—8 ; narrow and not very dark.
(180)	2—8 ; narrow.
(187)	2—8 ; weak.
(250)	Bands plain, but neither wide nor dark.
(282)	The six ordinary bands, but only 2, 3, and 7 are passably wide.

* In this case the carbon has not died out as early as it usually does, so that band 9 is seen in addition to 2—8.

Species 15.

No. of star.	Bands visible.
(41)	2 and 3 wide and dark, others feeble and narrow.
(50)* α Orionis.	1—10 ; rather pale and narrow.
(96)	Bands very narrow ; 2 and 3 strongest.
(101)	2 and 3 very well seen, 7 and 8 weak, 4 and 5 doubtful.
(136)	Bands in the red are wide, the others narrow.
(139)	Bands weak and narrow. Something like the spectrum of Aldebaran.
(147)	2, 3, 7 ; others extremely narrow.
(190)	2, 3, 7, narrow bands ; the rest almost like lines.
(226)	Feebly developed, 2 and 3 strongest.
(235)	Bands neither wide nor dark ; feebly developed.
(265)	Bands plainly seen, but extremely narrow.
(279)	2, 3, 7 dark, not very wide ; 4 and 5 narrow.

* The additional bands seen in this "star" are in all probability due to its great brilliancy as compared with other members of the group.

Indefinite—Early Stages.

No. of star.	Bands visible.
(3)	Bands weak, but very wide, especially in the green and blue.
(11)	Bands wide, especially in the green and blue.
(21)	Bands wide and dark, especially in the green and blue.
(34)	Bands dark, but rather narrow.
(45)	Bands wide; those in the blue are stronger than those in the red.
(59)	Fairly well developed; 4 and 5 narrow.
(68)	Bands wide and dark, especially in the green and blue.
(72)	Feebly developed; bands widest in green and blue.
(81)	Feebly developed; 7 and 8 are best visible.
(100)	Bands wide and dark, especially 7 and 8.
(106)	Bands dark, and wide in the blue and green.
(134)	Bands wide and dark, especially in green and blue.
(151)	Bands wide and dark, especially in the green and blue.
(159)	Bands in blue and green are very wide and dark.
(165)	Bands wide and well seen, especially in green and blue.
(168)	Bands wide and strong, especially in the green and blue.
(170)	The bands in the blue are very wide.
(192)	Bands are wide, especially in the green and blue.
(201)	Bands wide and well seen, especially 7 and 8.
(206)	Bands easily seen in green and blue; feebly developed.
(209)	Bands well seen, especially in green and blue.
(222)	Bands wide and dark, especially in green and blue.
(223)	Bands visible throughout the spectrum, strongest in green and blue.
(224)	Bands in green and blue are very wide and dark.
(248)	Bands dark and visible even in the blue.
(262)	Bands visible even in the blue, weakest in the red.

Indefinite—Later Stages.

No. of star.	Bands visible.
(8)	Bands pretty wide, and visible even in blue.
(10)	Bands enormously wide.
(14)	Bands narrow and dark throughout the spectrum, but especially in the red.
(35)	Feebly developed, but the bands seem to be wide.
(43)	Bands enormously wide, but very feeble.
(47)	Bands wide, spectrum weak.
(77)	Bands wide and dark in the red, weaker in the blue and green.
(80)	Bands wide, but not very dark; seen in blue also.
(84)	Feebly developed, but 2—8 are seen (Dunér's "feebly developed" means much developed from my point of view, if the bands are thin).
(102)	Bands wide, but pale.
(114)	Bands wide and pale, except 2 and 3, which are strong.
(119)	Bands wide throughout the spectrum.
(125)	Bands wide and pale, but visible even in the blue.
(127)	Bands wide, but very pale.
(157)	Bands wide, but pale.
(163)	Bands are pale, but visible even in the blue.
(210)	Bands wide, but feeble.
(213)	Bands in the red well marked; 4 and 5 weaker.
(219)	The six ordinary bands are seen, but they are rather pale.
(231)	Bands not very dark, but wide and visible even in the blue.
(236)	Bands wide, but weak.

Totally Indeterminate, on account of Absence of Details.

No. of star.	Bands visible.
(13)	Feebly developed. (No details given.)
(31)	Feebly developed.
(58)	Feebly developed; bands very indistinct.
(63)	Doubtful whether III*a* or III*b*.
(73)	Only recognised as III*a* on one occasion.
(79)	Feebly developed.
(85)	Doubtful whether III*a* or III*b*.
(105)	Feebly developed; somewhat uncertain.
(128)	Very feebly developed.
(178)	Feebly developed.
(238)	Feebly developed.
(257)	Very feebly developed.
(261)	Very feebly developed.
(272)	Not well marked.
(296)	? III*a*.

[Received April 5, 1888.]

Part V.—On the Cause of Variation in the Light of Bodies of Groups I and II.

I. General Views on Variability.

In my former paper I referred to the collision of meteor-swarms as producing "new stars," and to the periastron passage of one swarm through another as producing the more or less regular variability observed in the case of some stars of the group under consideration.

I propose now to consider this question of variability at somewhat greater length, but only that part of it which touches non-condensed swarms; *i.e.*, I shall for the present leave the phenomena of new stars, and of those whose variability is caused by eclipses, aside.

It is not necessary that I should pause here to state at length the causes of stellar variability which have been suggested from time to time. It will suffice, perhaps, that I should refer to one of the first suggestions which we owe to Sir I. Newton, and to the last general discussion of the matter, which we owe to Zöllner ('Photometrische Untersuchungen,' 76 and 77, p. 252).

Newton ascribed that special class of variability, to which I shall have most to refer in the sequel, as due to the appulse of comets.

"Sic etiam stellæ fixæ, quæ paulatim expirant in lucem et vapores, cometis in ipsas incidentibus refici possunt, et *novo alimento accensæ pro stellis novis haberi*. Hujus generis sunt stellæ fixæ, quæ subito apparent, et sub initio quam maxime splendent, et subinde paulatim evanescunt. Talis fuit stella in cathedra Cassiopeiæ quam Cornelius Gemma octavo Novembris 1572 lustrando illam cœli partem nocte serena minime vidit; at nocte proxima (Novem. 9) vidit fixis omnibus splendidiorem, et luce sua vix cedentem Veneri. Hanc Tycho Brahæus vidit undecimo ejusdem mensis ubi maxime splenduit; et ex eo tempore paulatim decrescentem et spatio mensium sexdecim evanescentem observavit" ('Principia,' p. 525, Glasgow, 1871).

With regard to another class of variables he makes a suggestion which has generally been accepted since :—

"Sed fixæ, quæ per vices apparent et evanescunt, quæque paulatim crescunt, et luce sua fixas tertiæ magnitudinis vix unquam superant, videntur esse generis alterius, et revolvendo partem lucidam et partem obscuram per vices ostendere. Vapores autem, qui ex sole et stellis fixis et caudis cometarum oriuntur, incidere possunt per gravitatem suam in atmosphæras planetarum et ibi condensari et converti in aquam et spiritus humidos, et subinde per lentum calorem in sales et sulphura et tincturas et limum et lutum et argillam et arenam et lapides et coralla et substantias alias terrestres paulatim migrare."

Zöllner in point of fact advances very little beyond the views advocated by Newton and Sir W. Herschel. He considers the main causes of variability to be as follows. He lays the greatest stress upon an advanced stage of cooling, and the consequent formation of scoriæ which float about on the molten mass. Those formed at the poles are driven towards the equator by the centrifugal force, and by the increasing rapidity of rotation they are compelled to deviate from their course. These facts, and the meeting which takes place between the molten matter, flowing in an opposite direction, influence the form and position of the cold non-luminous matter, and hence vary the rotational effects, and therefore the luminous or non-luminous appearance of the body to distant observers.

This general theory, however, does not exclude other causes, such as, for instance, the sudden illumination of a star by the heat produced by collision of two dark bodies, variability produced by the revolution of a dark body, or by the passage of the light through nebulous light-absorbing masses.

If the views I have put forward are true, the objects now under consideration are those in the heavens which are least condensed. In this point, then, they differ essentially from all true stars like the sun.

This fundamental difference of structure should be revealed in the phenomena of variability; that is to say—The variability of the bodies we are now considering should be different in *kind* as well as in degree from that observed in some cases in bodies like the sun or α Lyræ, taken as representing highly condensed types. There is also little doubt I think, that future research will show that when we get short-period variability in bodies like these, we are here really dealing with the variability of a close companion.

II. On the Variability in Group I.

That many of the nebulæ are variable is well known, though so far as I am aware there are no complete records of the spectroscopic result of the variability. But bearing in mind that in some of these bodies we have the olivine line by itself, and in others, which are usually brighter, we have the lines of hydrogen added, it does not seem unreasonable to suppose that any increase of temperature brought about by the increased number of collisions should add the lines of hydrogen to the spectrum of a nebula in which they were not previously visible.

The explanation of the hydrogen in the variable *stars* is not at first so obvious, but a little consideration will show that this must happen if my theory be true.

Since the stars with bright lines are, as I have attempted to show,

very akin to nebulæ in their structure, we might, reasoning by analogy, suppose that any marked variability in their case also would be accompanied by the coming out of the bright hydrogen lines.

This is really exactly what happens both in β Lyræ and in γ Cassiopeiæ. In β Lyræ the appearance of the lines of hydrogen has a period of between six and seven days, and in γ Cassiopeiæ they appear from time to time, although the period has not yet been determined.

III. On the Variability in Group II.

This same kind of variability takes place in stars with the bright flutings of carbon indicated in their spectra, *o* Ceti being a marvellous

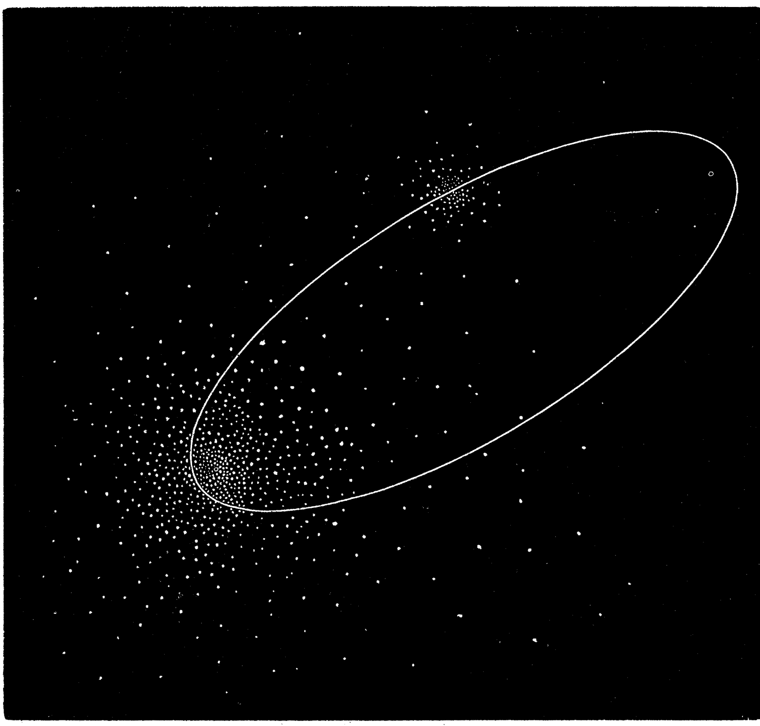

Fig. 17.—Explanation of the variability of bodies of Group II. (1.) Maximum variation. The ellipse represents the orbit of the smaller swarm, which revolves round the larger. The orbit of the revolving swarm is very elliptical, so that at periastron the number of collisions is enormously increased.

case in point. In α Orionis, one of the most highly developed of these stars, the hydrogen lines are invisible; the simple and sufficient explanation of this being that, as I have already suggested, the bright lines from the interspaces now at their minimum and containing

vapours at a very high temperature—*teste* the line-absorption spectrum now beginning to replace the flutings—balance the absorption of the meteoric nuclei.

Anything which in this condition of light-equilibrium will increase the amount of incandescent gas and vapour in the interspaces will bring about the appearance of the hydrogen lines as bright ones. The thing above all things most capable of doing this in a most transcendental fashion is the invasion of one part of the swarm by

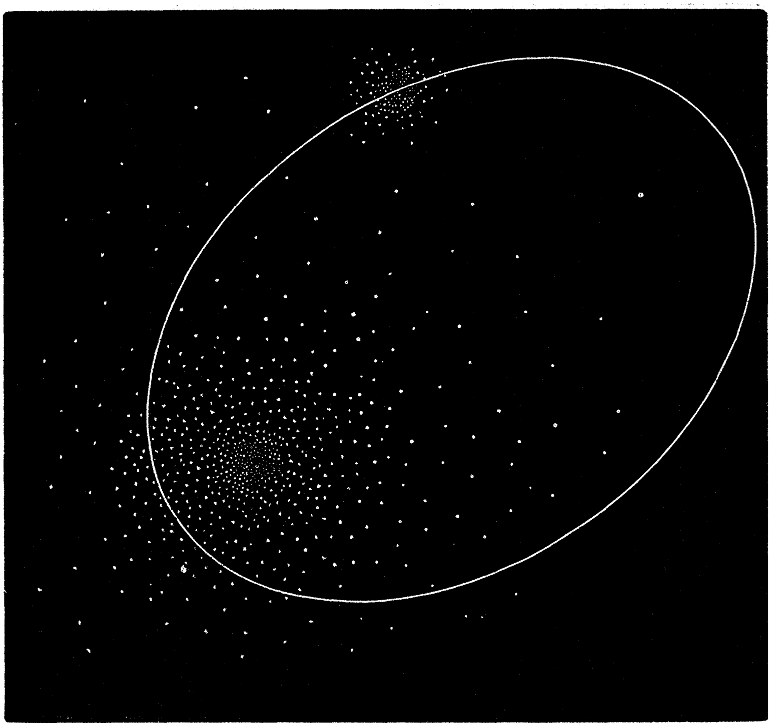

FIG. 18.—Explanation of the variability of bodies of Group II. (2.) Medium variation. In this case, there will be a greater number of collisions at periastron than at other parts of the orbit. The variation in the light, however, will not be very great under the conditions represented, as the revolving swarm never gets very near the middle of the central one.

another one moving with a high velocity. This is exactly what I postulate. The wonderful thing under these circumstances then would be that bright hydrogen should *not* add itself to the bright carbon, not only in bright-line stars, but in those the spectrum of which consists of mixed flutings, bright carbon representing the radiation.

I now propose to use this question of variability in Group II as a further test of my views.

The first test we have of the theory is that there should be more variability in this group than in any of the others. Others are as follows: (2) When the swarm is most spaced, we shall have the least results from collisions, but (3) when it is fairly condensed, the effect at periastron passage (if we take the simplest case of a double star *in posse*) will be greatest of all, because (4) condensation may ultimately bring the central swarm almost entirely within the orbit of the secondary (cometic) body, in which case no collisions could happen.

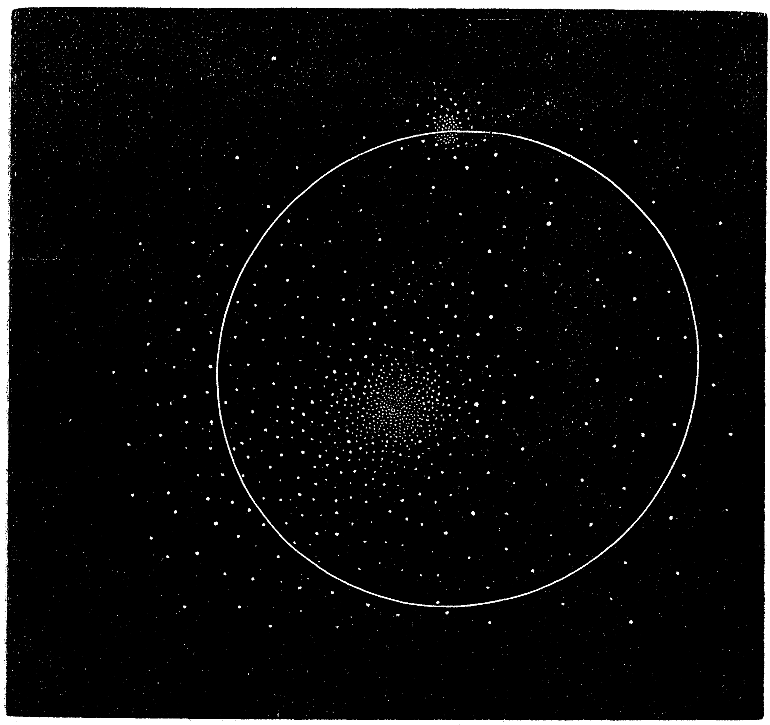

FIG. 19.—Explanation of the variability of bodies of Group II. (3.) Minimum variation. Under the conditions shown, the smaller swarm will never be entirely out of the larger one, and at periastron the number of collisions will not be very greatly increased. Consequently, the variation in the amount of light given out will be small.

In the light of what has gone before it is as easy to test these points as the former ones.

The Frequent Occurrence of Variability in Group II.

The total number of stars included in Argelander's Catalogue, which deals generally with stars down to the ninth magnitude, but in

which, however, are many stars between the ninth and tenth, is 324,118. The most complete catalogue of variables (without distinction) that we have has been compiled by Mr. Gore, and published in the 'Proceedings of the Royal Irish Academy' (series ii, vol. 4, No. 2, July, 1884, pp. 150—163). I find 191 known variables are given; of these 111 are in the northern hemisphere and 80 in the southern hemisphere.

In the catalogue of *suspected* variable stars given in No. 3 of the same volume (January, 1885, pp. 271—310), I find 736 stars, of which 381 are in the northern and 355 in the southern hemisphere.

Taking, then, those in the northern hemisphere, both known and suspected, we have the number 492.

We have then as a rough estimate for the northern heavens one variable to 659 stars taken generally.

The number of objects of Group II observed by Dunér, and recorded in his admirable memoir, is 297; of these forty-four are variable.

So that here we pass from 1 in 657 to 1 in 7.

Of the great development of variability-conditions in this group then there can be no question.

To apply the other tests above referred to, I have made a special study of the observations of each variable recorded by Dunér. I find they may be grouped in the following

Table of Variables.

1. All bands visible but narrow.

No. in Dunér Cat.	Name.	Max.	Min.	Period.	
269	μ Cephei	4 ?	5 ?	irreg.	

2. Bands well marked, but feebler in Red.

No. in Dunér Cat.	Name.	Max.	Min.	Period.	
186	W Herculis (? V)..	>8	<12	290 ?	
222	R Sagittarii	7	12	270	
81	S Hydræ	7·8	<12	256	

3. Bands wide and strong, especially 7 and 8.

No. in Dunér Cat.	Name.	Max.	Min.	Period.	
23	T Arietis	8	9—10	324	
37	R Tauri..........	7·8	< 13	326	
68	S Canis Min.	7	< 11	332	
76	R Cancri.........	6	< 11—12	360	
91	R Leonis Min.	5	10	313	
100	R Urs. Maj.......	6	12	303	
106	R Crateris........	> 8	< 9	160 ?	
118	R Corvi..........	7	< 11 – 13	319	
159	R Boötis.........	6	12	223	
165	S Libræ..........	8	12—13	190 ?	
170	R Serpentis	5·6	< 11	358	
181	U Herculis	6·7	11—12	408	
192	S Herculis	6	12	303	
195	R Ophiuchi	7·8	12	302	

4. All bands markedly wide and strong.

No. in Dunér Cat.	Name.	Max.	Min.	Period.	
18	*o* Ceti	2—5	8—9	(331)	
20	R Ceti	8	< 13 ?	167	
29	*ρ* Persei	3 ·4	4 ·2	irreg.	Many lines.
92	R Leonis	5	10	313	
141	R Hydræ.........	4 ·5	40 ?	(437)	
158	V Boötis	..	..	..	
166	S Coronæ	6	12	361	
184	*g* Herculis........	5	6	irreg.	
196	*a* Herculis........	3	4	irreg.	
217	R Lyræ	4 ·3	4 ·6	46	
221	R Aquilæ	6 ·7	11	345	
239	*χ* Cygni	4	13	406	
293	R Aquarii	6	11	388	

5. Bands wide, but pale.

No. in Dunér Cat.	Name.	Max.	Min.	Period.	
3	T Cassiopeiæ	6·7	11	436	
125	T Urs. Maj.	7	12	256	
127	R Virginis	6·7	11	146	
157	R Camel.	8	12?	266	
231	R Cygni..........	6	13	425	
281	β Pegasi.........	7	12	382	
	T Herculis	7	12	165	
4	R Androm.	5·6	< 12—13	405	

6. Bands thin and pale.

No. in Dunér Cat.	Name.	Max.	Min.	Period.	
50	α Orionis	1	1·4	irreg.	
128	S Urs. Maj.	7·8	11	225	
187	R Draconis	6·7	11—12	247	
238	S Vulpec.				
261	R Vulpec.........	7·8	13	137	

A glance at the above tables will show that the kind of variability presented by these objects is a very special one, and is remarkable for its great range. The light may be stated in the most general terms to vary about six magnitudes—from the sixth to the twelfth. This, I think, is a fair average; the small number of cases with a smaller variation I shall refer to afterwards. A variation of six magnitudes means roughly that the variable at its maximum is somewhere about 250 times brighter than at its minimum.*

I have already indicated that, with regard to the various origins of the variability of stars which have been suggested, those which have been always most in vogue consider the maximum luminosity of the star as the normal one; and, indeed, with regard to the Algol type of

* Obtained by the formula $L_m = (2{\cdot}512)^n \, . \, L_{m+n}$.

For differences of 5, 6, 7 and 8 mag. we get

$$\begin{aligned} L_m &= 100{\cdot}02 \, . \, L_{m+5} \\ &= 251{\cdot}24 \, . \, L_{m+6} \\ &= 631{\cdot}11 \, . \, L_{m+7} \\ &= 1585{\cdot}35 \, . \, L_{m+8} \end{aligned}$$

L_m = light of a star of magnitude m.

L_{m+n} = ,, ,, n magnitudes fainter.

stars of short period, which obviously are not here in question, there can be no reasonable doubt, that the eclipse explanation is a valid one; but in cases such as we are now considering, when we may say that the ordinary period is a year, this explanation is as much out of place on account of period, as are such suggested causes as stellar rotation and varying amount of spotted area on a stellar surface, on account of range.

We are driven, then, to consider a condition of things in which the minimum represents the constant condition, and the maximum a condition imposed by some cause which produces an excess of light; so far as I know the only explanation on such a basis as this that has been previously offered is the one we owe to Newton, who suggested such stellar variability as that we are now considering was due to conflagrations brought about at the maximum by the appulse of comets.

How the Difficulty of Regular Variability on Newton's View is got over in mine.

It will have been noticed that the suggestion put forward by myself is obviously very near akin to the one put forward by Newton, and no doubt his would have been more thoroughly considered than it has been hitherto, if for a moment the true nature of the special class of bodies we are now considering had been *en évidence*. We know that some of them at their minimum put on a special appearance of their own in that haziness to which I have before referred as having been observed by Mr. Hind. My researches show that they are probably nebulous, if indeed they are not all of them planetary nebulæ in a further stage of condensation, and such a disturbance as the one I have suggested would be certain to be competent to increase the luminous radiations of such a congeries to the extent indicated.

Some writers have objected to Newton's hypothesis on the ground that such a conflagration as he pictured could not occur periodically; but this objection I imagine chiefly depended upon the idea that the conflagration brought about by one impact of this kind would be quite sufficient to destroy one or both bodies, and thus put an end to any possibilities of rhythmically recurrent action. It was understood that the body conflagrated was solid like our earth. However valid this objection might be as urged against Newton's view, it cannot apply to mine, because in such a swarm as I have suggested, an increase of light to the extent required might easily be produced by the incandescence of a few hundred tons of meteorites.

I have already referred to the fact that the initial species of the stars we are now considering have spectra almost cometary, and this leads us to the view that we may have among them in some cases swarms

with double nuclei—incipient double stars, a smaller swarm revolving round the larger condensation, or rather round their common centre of gravity. In such a condition of things as this, it is obvious that, as before stated, in the swarms having a mean condensation this action is the more likely to take place, for the reason that at first the meteorites are too sparse for many collisions to occur, and that, finally, the outliers of the major swarm are drawn within the orbit of the smaller one, so that it passes clear. The tables show that this view is entirely consistent with the facts observed, for the greater number of instances of variability occur in the case of those stars in which on other grounds mean spacing seems probable.

The Cases of Small Range.

So far, to account for the greatest difference in luminosity at periastron passage, we have supposed the minor swarm to be only involved in the larger one during a part of its revolution, but we can easily conceive a condition of things in which its orbit is so nearly circular that it is almost entirely involved in the larger swarm. Under these conditions, collisions would occur in every part of the orbit, and they would only be more numerous at periastron in the more condensed central part of the swarm, and it is to this that I ascribe the origin of the phenomena in those objects—a very small number—in which the variation of light is very far below the normal range, one or two magnitudes instead of six or seven. Of course, if we imagine two subsidiary swarms, the kind of variability displayed by such objects as β Lyræ is easily explained.

Study of Light Curves.

I owe to the kindness of Mr. Knott the opportunity of studying several light curves of " stars " of this group, and they seem to entirely justify the explanation which I have put forward. It is necessary, however, that the curves should be somewhat carefully considered because in some cases the period of the minimum is extremely small, as if the secondary body scarcely left the atmosphere of the primary one but was always at work. But when we come to examine the shape of the curves more carefully what we find is that the rise to maximum is extremely rapid; in the case of U Geminorum for instance there is a rise of five magnitudes in a day and a half; whereas the fall to minimum is relatively slow. The possible explanation of this is that the rise of the curve gives us the first sudden luminosity due to the collisions of the swarms, while the descent indicates to us the gradual toning down of the disturbance. If it be considered fair to make the descending curve from the maximum exactly symmetrical with the ascending one on the assumption that the immediate effect produced is absolutely instantaneous, then we find in all cases that I

have so far studied that the star would continue for a considerable time at its minimum.

Broadly speaking, then, we may say that the variables in this group are *close doubles.* The invisibility of the companion being due to the nearness to the primary or to its faintness.

Double Stars.

If, in connexion with this subject, we refer to the various observations which have been made of double nebulæ and stars, we are driven to the conclusion that in many cases a double star has at one time existed as a double nebula, while on the other hand, from what has been stated it seems probable that in many cases the companion is a late addition to the system. It would seem as if we may be able in the future, by observing the spectra of double stars, or possibly even their colours when once each particular colour has been attached to a particular spectrum, to discriminate between these two conditions.

In discussing this matter, however, a difficulty arises on account of the fact that on the new view there will be no constant relation between the mass of a swarm and its brightness. When we see a "star" of a certain magnitude, we cannot tell from its brightness alone whether it is a large faint one or a small bright one, for a large body at a low temperature may be equalled or even excelled in brightness by a smaller "star" at a higher temperature. But when we know the spectra of the bodies, we also know their relative temperatures. In the absence of spectroscopic details, colour helps us to a certain extent.

If a pair of "stars" of unequal masses have condensed from the same nebulosity, the smaller one will be further advanced along the temperature curve than the larger one, and the colours and spectra will be different; *but it is not imperative that the magnitudes shall be unequal,* for the smaller swarm will for a time be considerably hotter than the larger one.

If the masses be very unequal, the smaller one will have the smaller magnitude for the longest time. Where there is a great difference in magnitude, therefore, it is generally fair to assume that the one with the smaller magnitude has also the smaller mass.

Another difficulty in the discussion, in the absence of spectroscopic details, is due to the similarity in colour of bodies at opposite points of the temperature curve. Thus, bodies in Group III have, as far as we at present know, exactly the same colour, namely, yellow, as those in Group V. Again, many of the members of Group II have the same colour as some in Group VI.

The general conditions with regard to this subject may be thus briefly stated:—If the *magnitudes*, colours, and spectra of the two

components of a physical double are identical, both had their origin in the same nebulosity.

If the *magnitudes* are nearly equal, but the colours and spectra different, it may be that the one with the most advanced spectrum has the smaller mass, and if the advance is in due proportion, we are justified in regarding them as having had a common origin.

If the *magnitudes* are very unequal, we may take the one with the smaller magnitude as having the smaller mass, and if it is proportionately in advance, as indicated by its spectrum or colour, we may regard both components as having had a common origin. If the smaller one be less advanced than the larger one, as most generally happens, we have to regard it as a late addition to the system.

If the two stars are of equal *mass* and revolve round their common centre of gravity they have in all probability done so from the nebulous stage, and therefore they will have arrived at the same stage along the evolution road, and their colours and spectra will be identical.

If, however, the *masses* are very different, then the smaller mass will run through its changes at a much greater rate than the larger one. In this way it is possible that the stars seen so frequently associated with globular nebulæ may be explained; while the nebula with a larger mass remains still in the nebulous condition, the smaller one may be advanced to any point, and may indeed even be totally invisible, while the parent nebula is still a nebula. This condition may be stated most generally by pointing to those double stars in which the companions are small and red, although we know nothing for certain with regard to their masses. But if we pass to the other category in which the companion is added afterwards, the most extreme form would be a nebula revolving round a completely formed star; a less extreme form would be a bright line star, or a star of the second group, revolving round it. In this case the colour would be blue or greenish-blue or gray; now this is the greatly preponderating condition, as I have gathered from a discussion of the colours of the small companions given in Smyth's 'Celestial Cycle'; and accepting these colours alone, we should be led to think that most of the small companions of our present stars were not companions originally, but represent later additions to the systems.

It is obvious that there are very many other questions of great interest lying round these considerations, but it is not necessary that I should refer at greater length to them on this occasion, as my present object is only to show that a consideration of the colours of double stars really adds weight to the cause of variability which I have suggested.

[Received April 9, 1888].

CONCLUSION.

Although in this paper I have chiefly confined myself to the discussion of the probable nature of the bodies in Groups I and II, I have also been engaged in the investigation of the spectra of some of the bodies included in the remaining groups, with a view to their detailed classification. Here, however, the work goes on slowly for lack of published material, especially with regard to the examination of the stars which should be included in Groups III and V. With regard to Group VI, however, I may state that all the stars the spectra of which have been recorded have been distributed among five well-marked species, and that there is evidence that some of the absorption is produced by substances which remain in the atmosphere during the next stage, that of Group VII. This probability is based upon the fact that some of the bands are apparently coincident with bands in the telluric spectrum as mapped by Brewster, Ångström, Smyth, and others.

In special connexion with the discussion of Groups I and II, the spectrum of the Aurora Borealis, concerning which I have already (January 19, 1888) communicated to the Society a preliminary note indicating the possible connexion between the spectra of the aurora and of stars of Group II, has been further studied. By this inquiry the work has been advanced a stage, and the view is strengthened that in the case of the aurora the spectrum is mainly one of metallic flutings and lines, probably produced by electric glows in an atmosphere charged with meteoric dust and the *débris* of shooting stars; while in bodies of Groups I and II it is chiefly produced by collisions between the component meteorites.

It may be thought by some premature to give an extended discussion of the bodies belonging to the two groups which have been dealt with before my view of their constitution has been thoroughly tested by observations. My reasons, however, for the present publication are twofold. I have not sufficient optical power at my disposal to go over the ground myself, and I have been anxious to save time by indicating to those who are at present occupied with stellar spectra, or who may be prepared to undertake such observations with sufficient optical appliances, the points chiefly requiring investigation as being of a crucial nature.

From this point of view the small number of observatories paying attention to these matters is much to be regretted, and the importance of Mrs. Draper's noble endowment of spectroscopic photography at Harvard College will be best appreciated.

I may, however, say that I have made some observations in the

clear air of Westgate-on-Sea, with a fine 12-inch mirror which has been kindly lent to me by Mr. Common, which have convinced me of the existence of bright carbon flutings in α Orionis. This is the most crucial observation I have been able to suggest.

The necessity for the employment of large apertures in the investigation is shown by the fact that with Mr. Common's mirror I was totally unable to see any lines in the spectrum of γ Cassiopeiæ except the red line of hydrogen.

The laboratory researches on the spectra of meteorites are also being continued. I am glad to be permitted to state that the meteorites employed from the commencement of my work are fragments of undoubted authenticity which have been placed at my disposal by the Trustees of the British Museum, and my best thanks are due to that body.

I have also to thank Professor Flower and Mr. Fletcher, the official in charge of the Mineral Department, for their kindness in giving me special facilities for studying our national collections.

Finally, as before, I have to thank my assistants, Messrs. Fowler, Taylor, and Richards for the manner in which they have helped me throughout these inquiries. Their intelligent and unflagging zeal have rendered me greatly their debtor.

I also wish to thank Mr. Collings for the care with which the illustrations have been prepared.

Presents, April 12, 1888.

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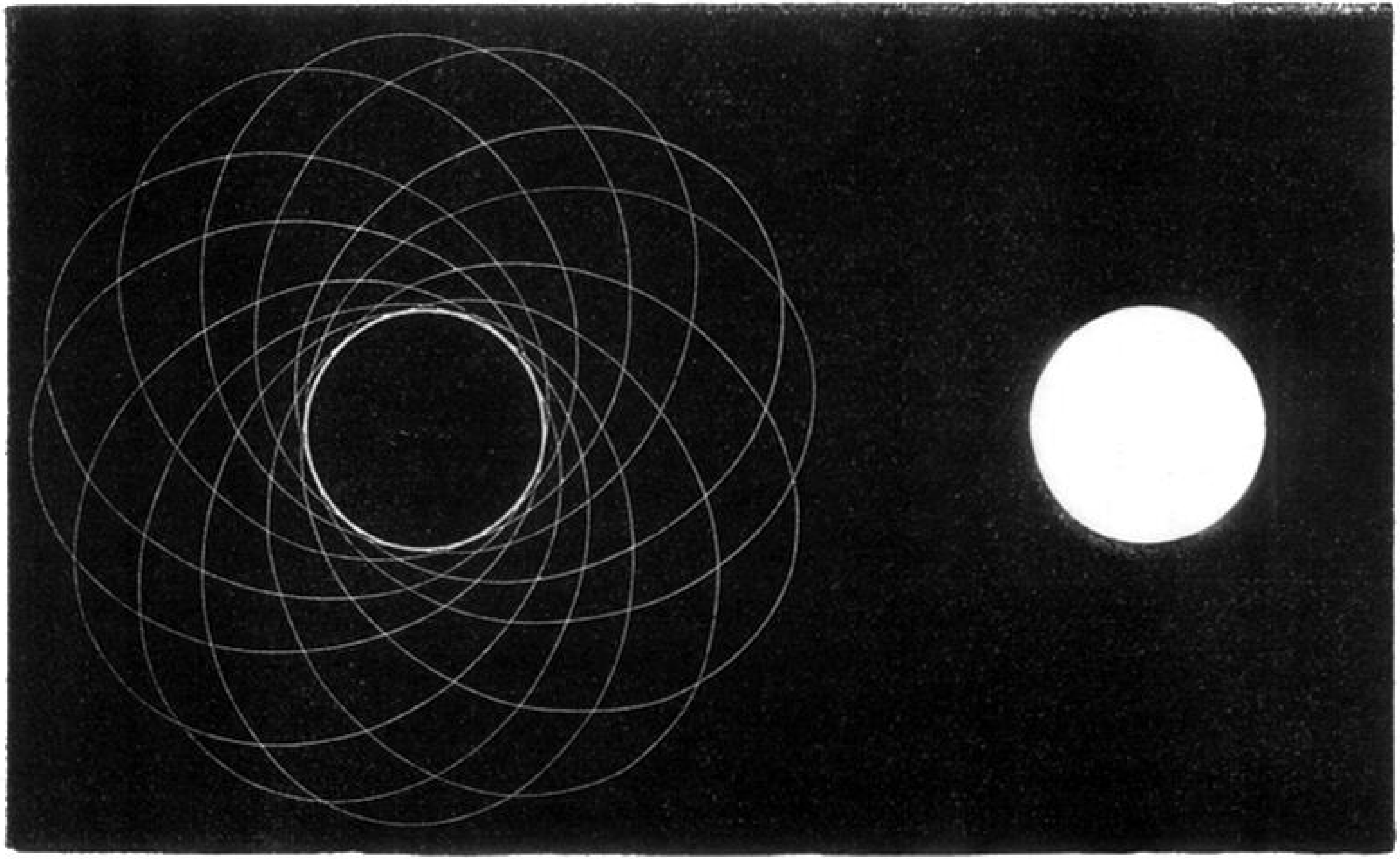

FIG. 1.—Suggested origin of the appearance presented by a planetary nebula. The luminosity is due to the collisions occurring along the sphere of intersection of the elliptic orbits of the meteorites. The left-hand diagram is a cross-section of the meteoric system, and the right-hand one shows the appearance of the collision-shell as seen from a point outside.

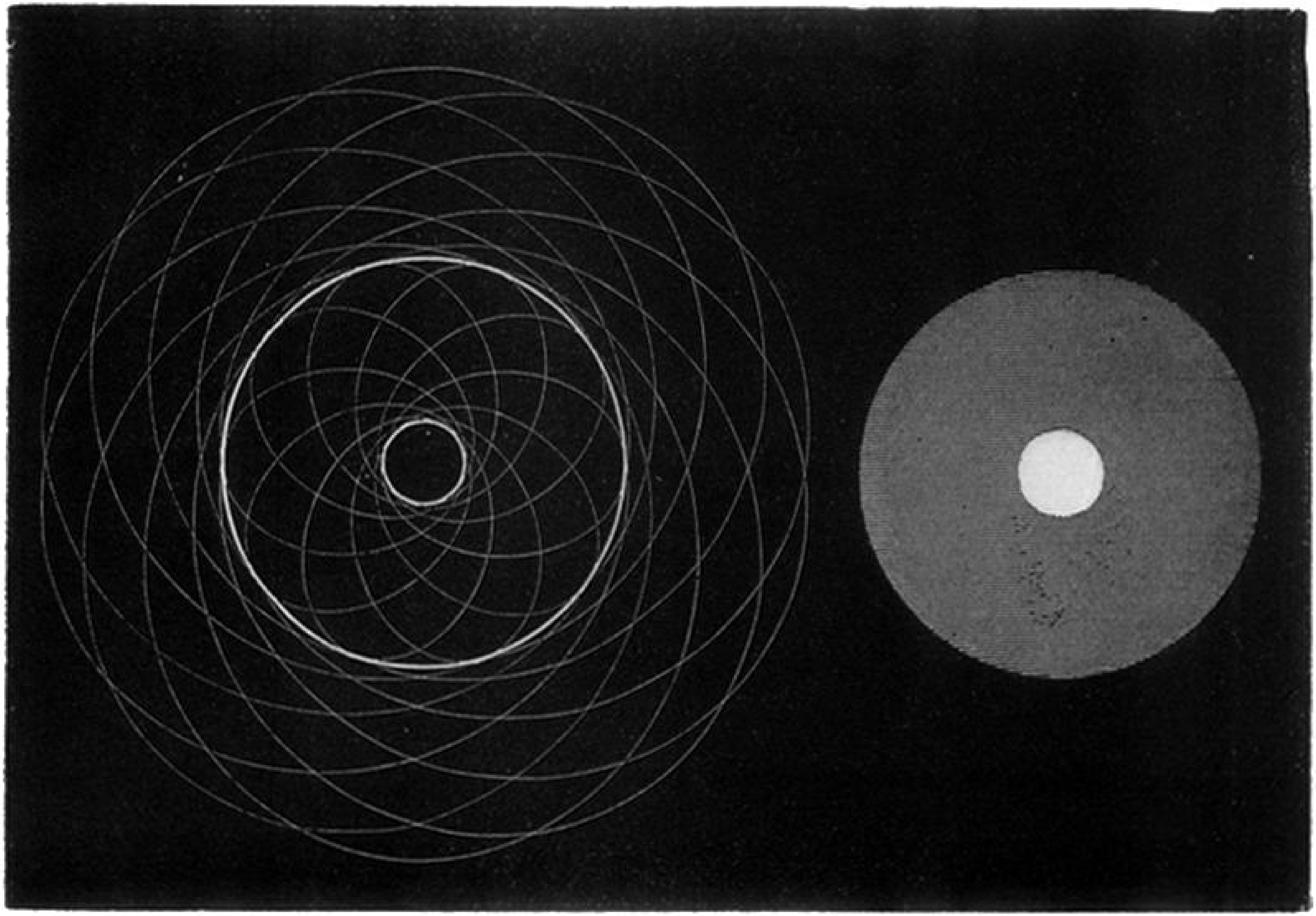

FIG. 2.--Suggestion as to the origin of a globular nebula with a brighter central portion. As in the former case, the luminosity of the fainter portion is due to the collisions which occur along the sphere of intersection represented by the larger circle. After collision the meteorites will travel in new orbits, and there will be an additional sphere of intersection, represented by the smaller circle. The left-hand diagram is a cross-section, and the right-hand one represents the appearance of the two collision-shells as seen from a point outside.

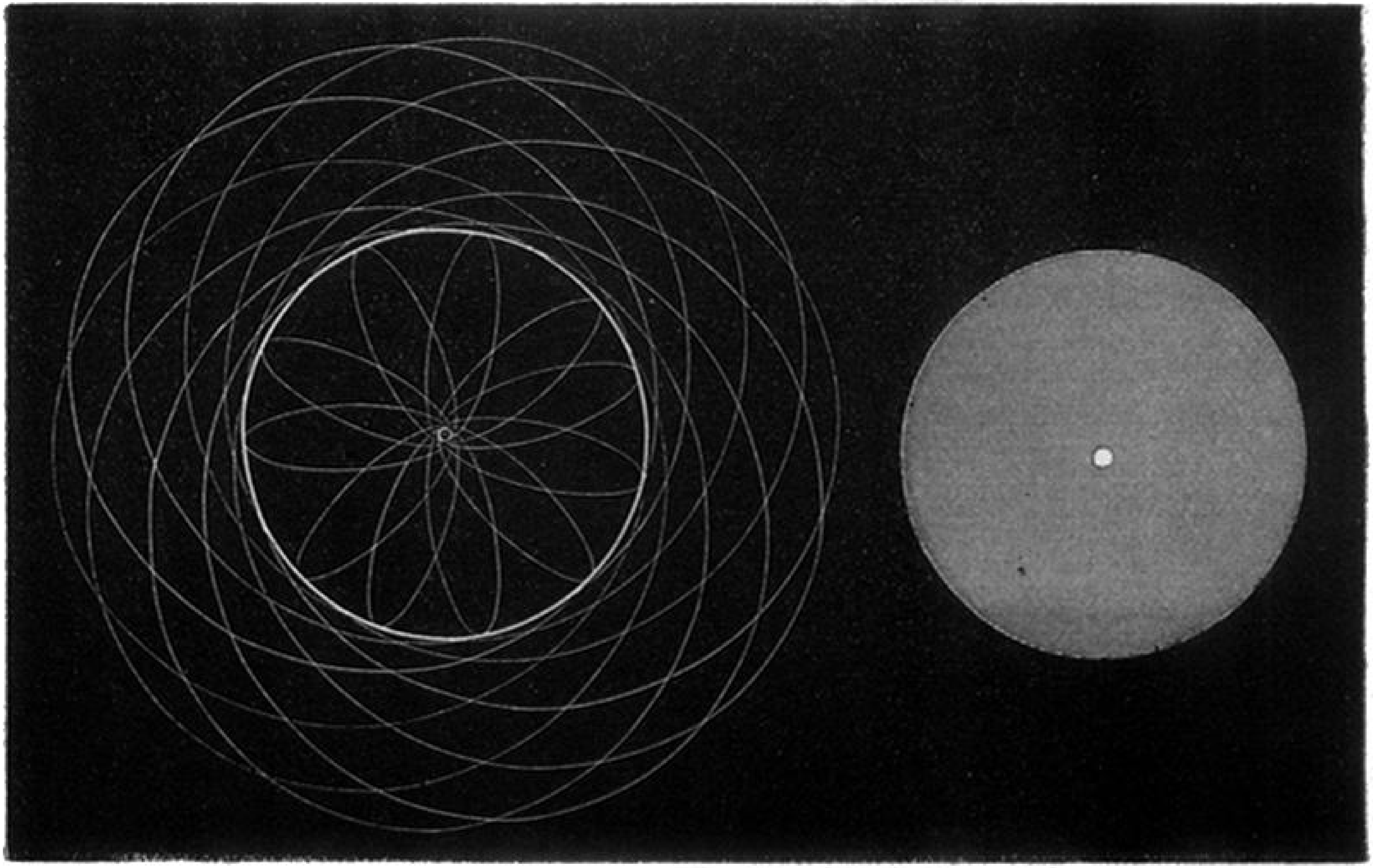

FIG. 3.—Suggestion as to the origin of a nebulous star. The orbits of the inner set of meteorites are very elliptic, so that the shell of intersection appears almost as a point. As in the previous cases, the left-hand diagram represents the meteoric systems in section, and the right-hand one the appearance from a point outside.

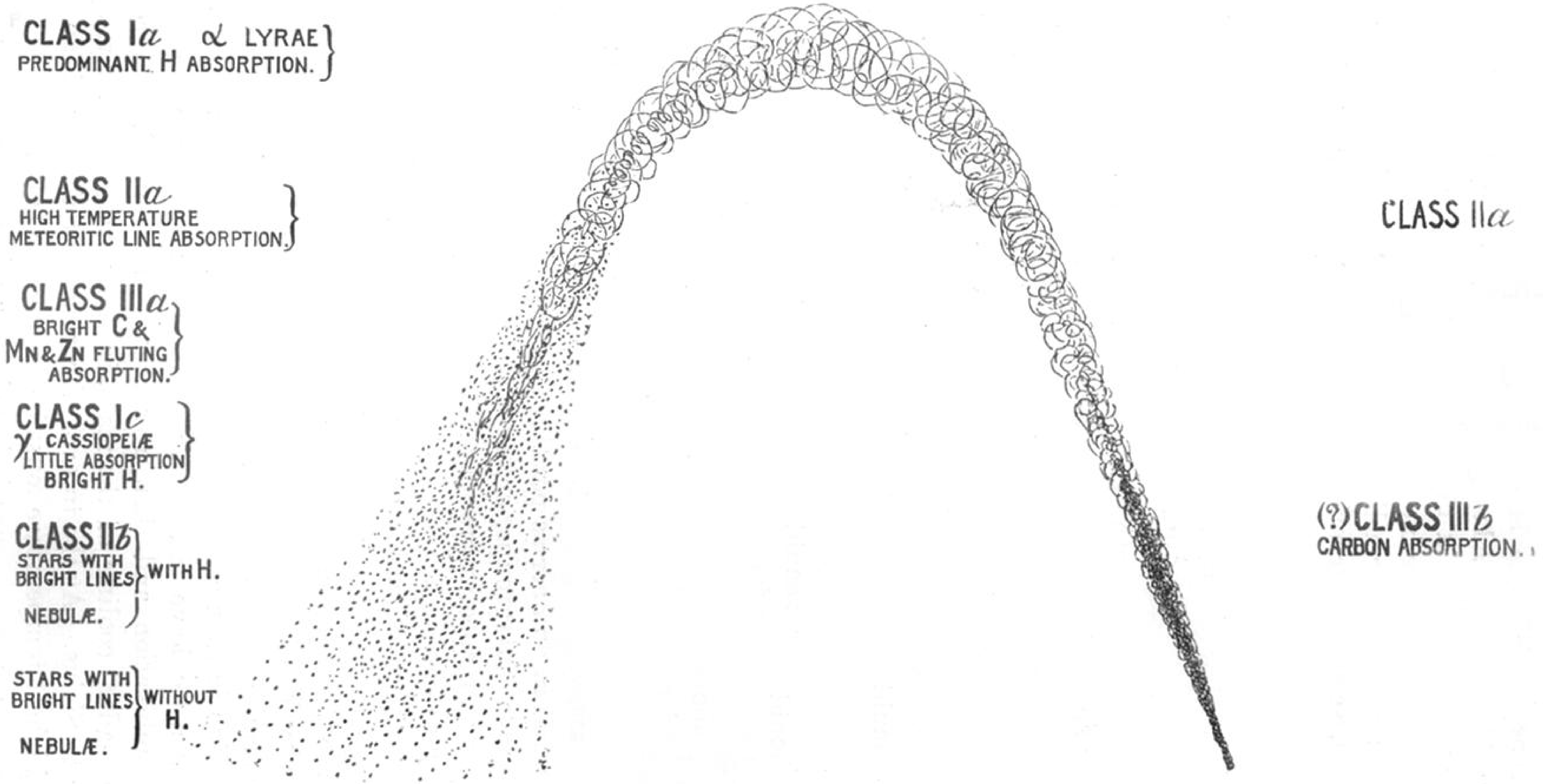

FIG. 4.—Temperature curve, showing the relative temperatures of the different orders of celestial bodies. The top of the curve represents the highest temperatures, and the bottom of each arm the lowest. On the left arm, the temperatures are increasing, on the right they are decreasing. The diagram shows the relative temperatures of Vogel's classes.

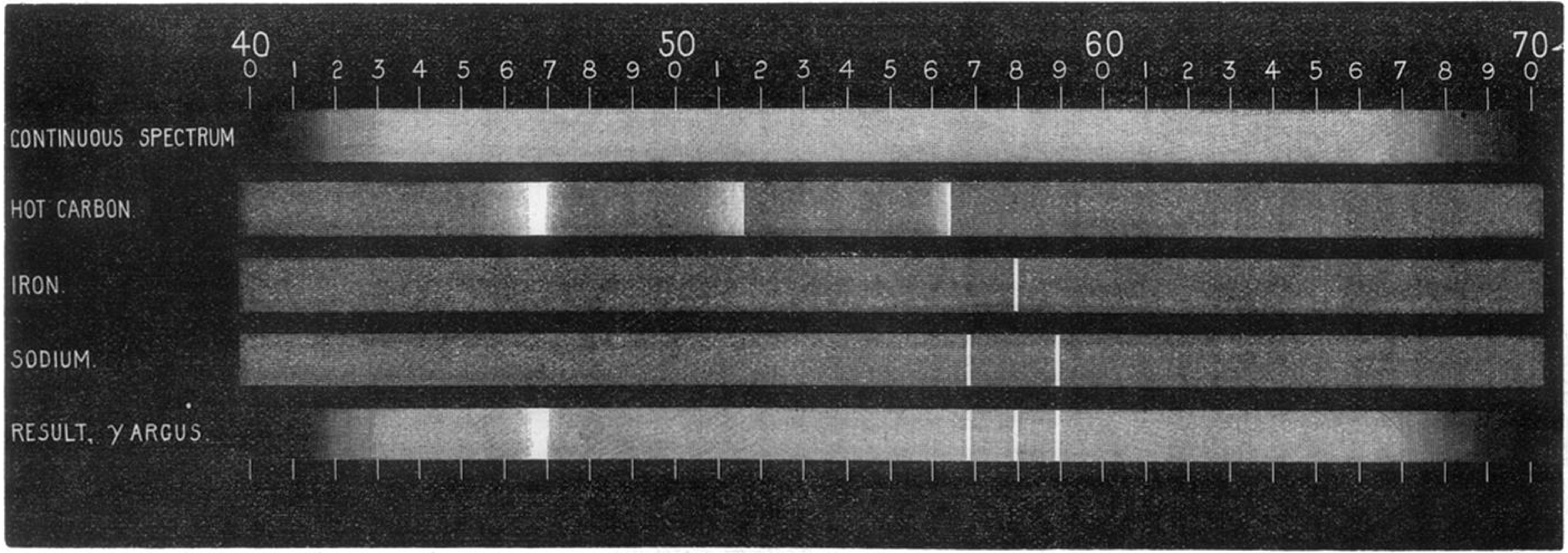

Fig. 5 (γ Argus).—Map showing the probable origin of the spectrum of γ Argus.

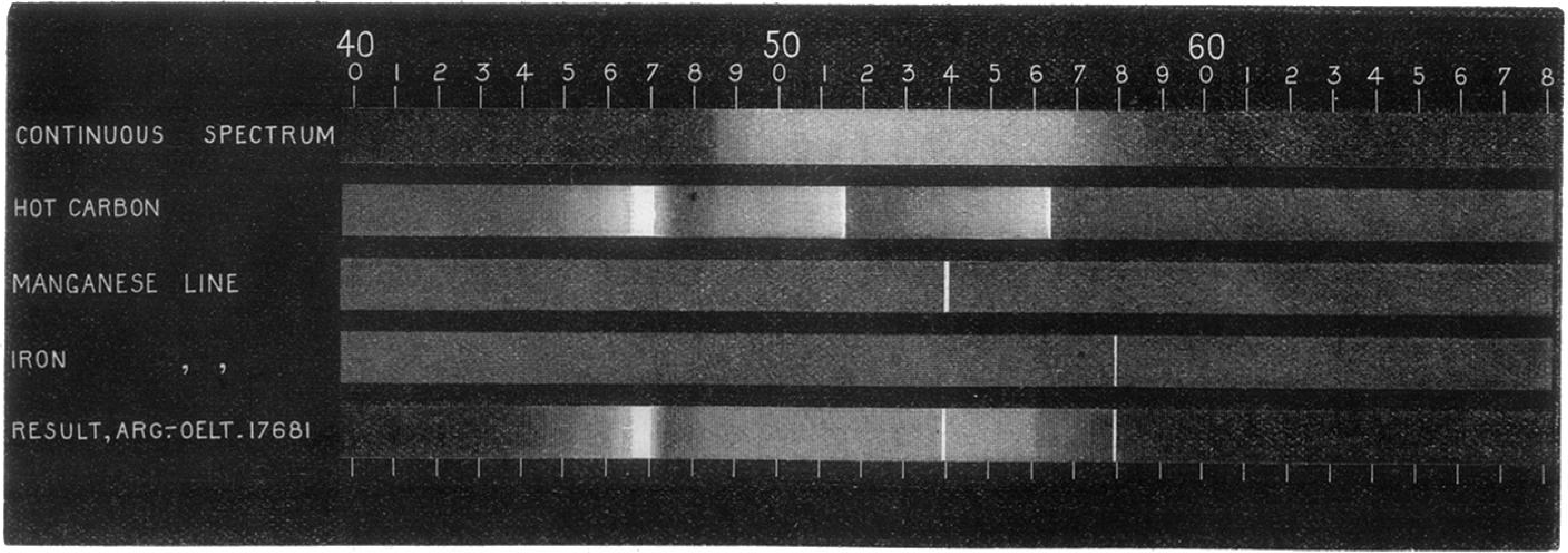

FIG. 6.—Map showing the probable origin of the spectrum of Argelander-Oeltzen 17681.

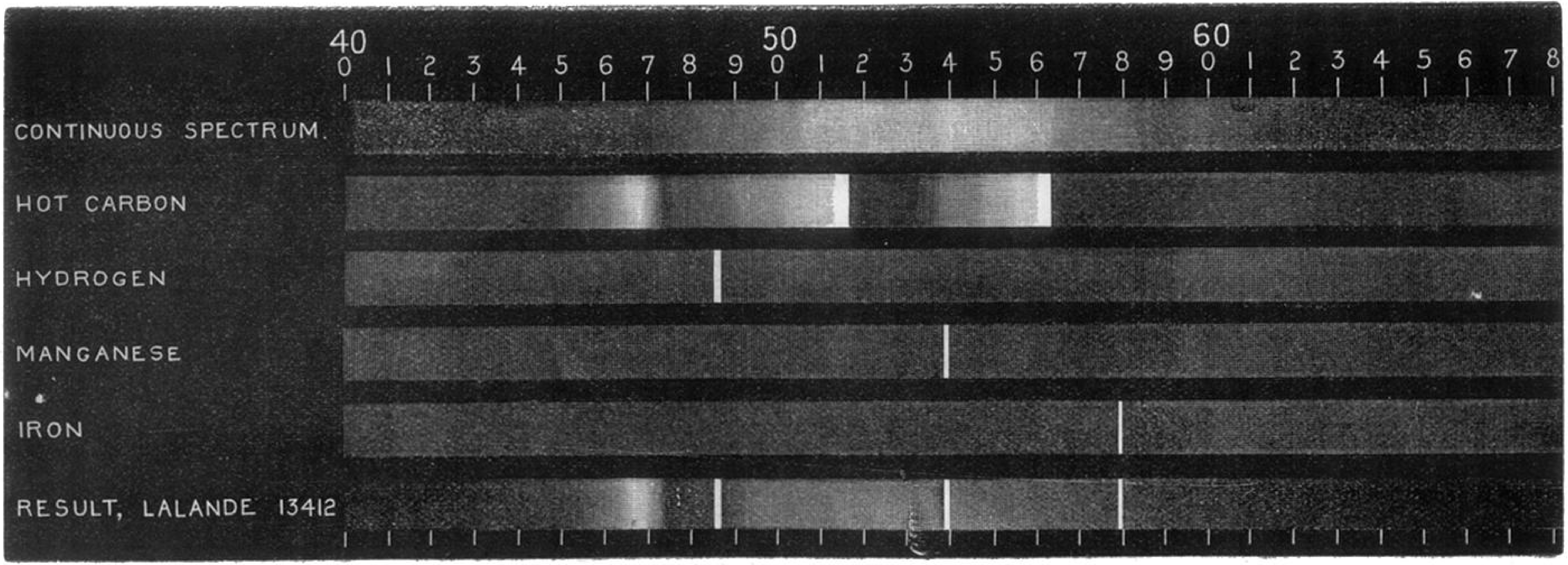

FIG. 7.—Map showing the probable origin of the spectrum of Lalande 13412.

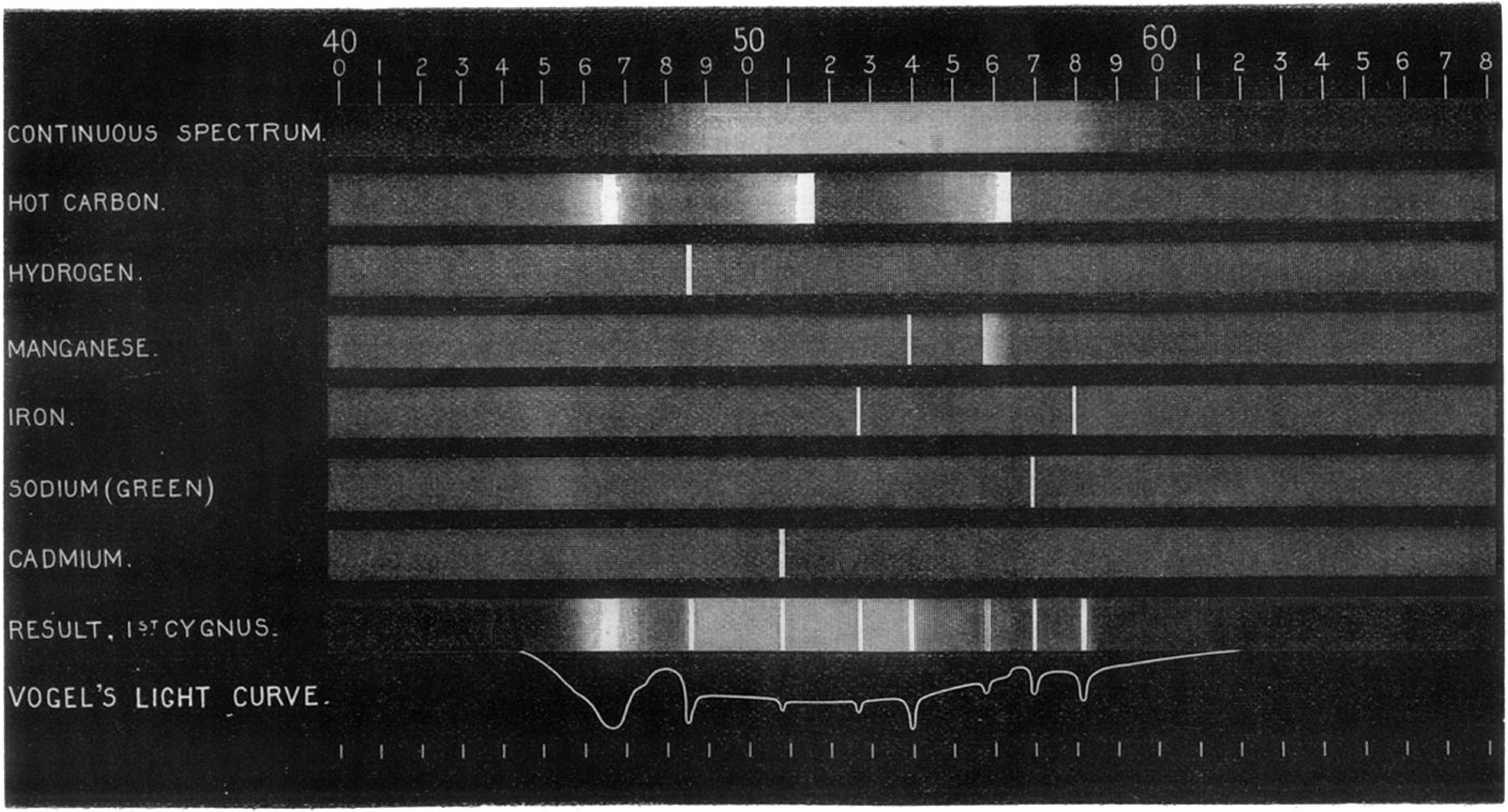

FIG. 8.—Map showing the probable origin of the spectrum of Wolf's and Rayet's 1st star in Cygnus.

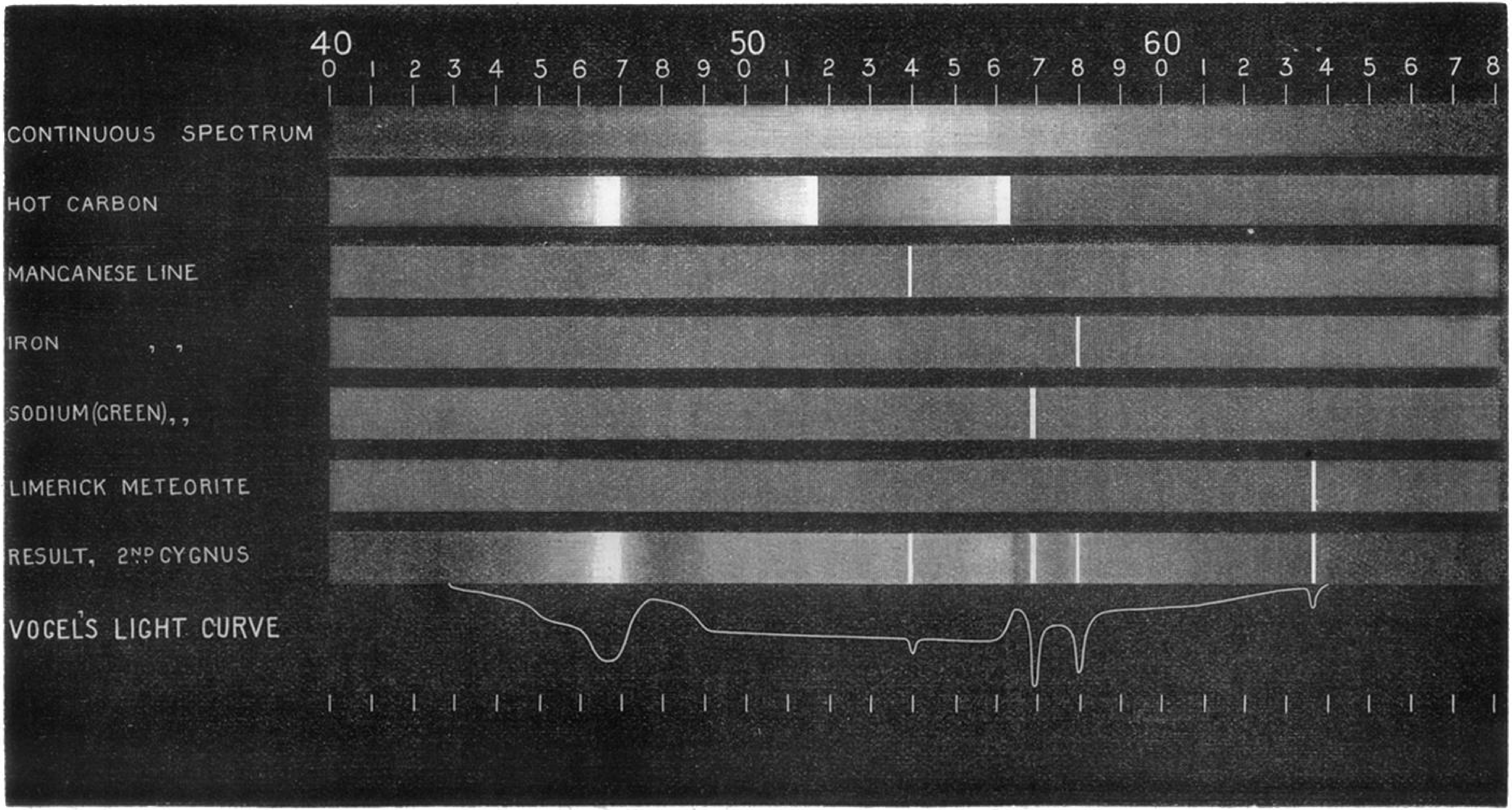

FIG. 9.—Map showing the probable origin of the spectrum of Wolf's and Rayet's 2nd star in Cygnus.

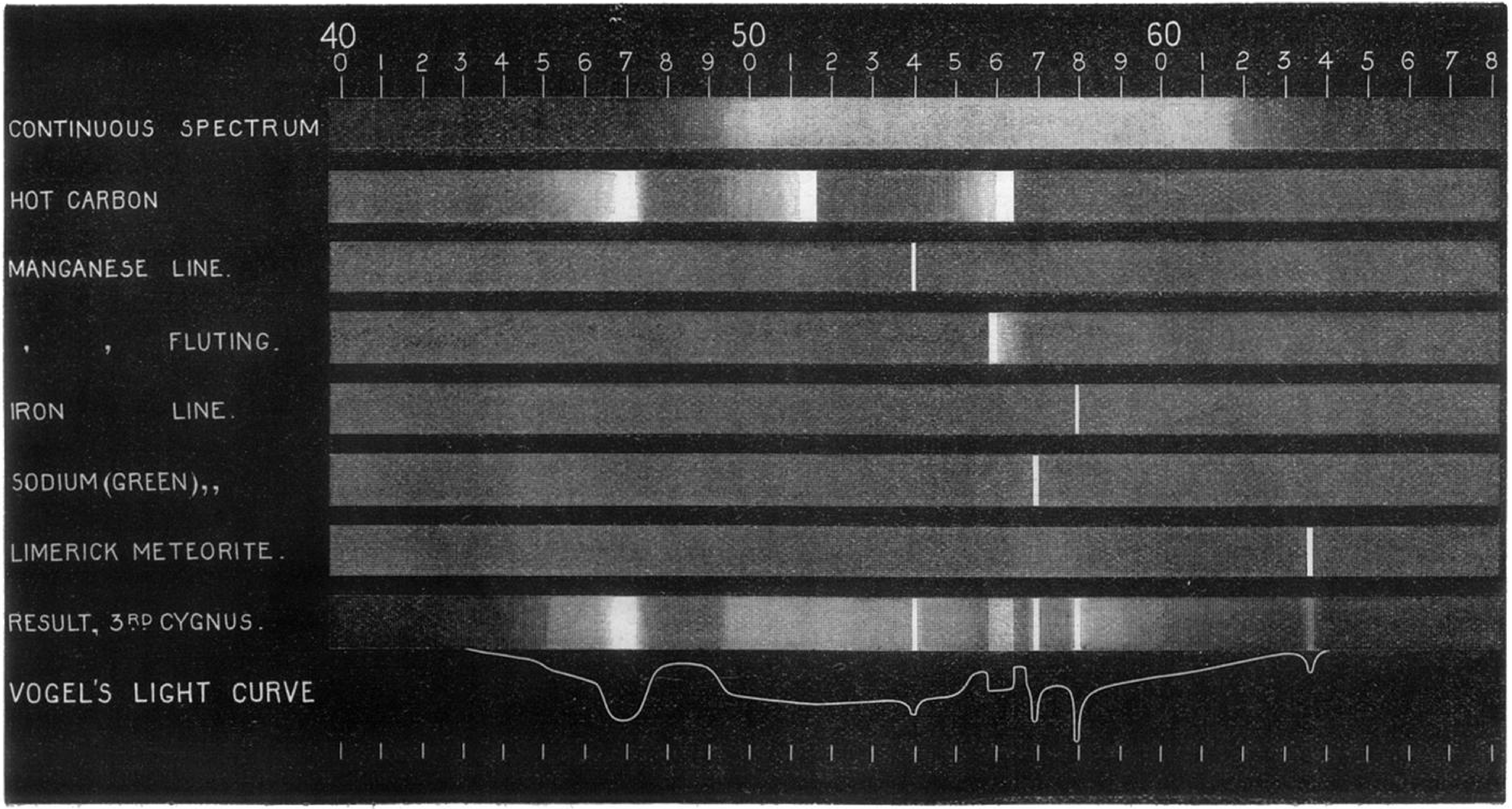

FIG. 10.—Map showing the probable origin of the spectrum of Wolf's and Rayet's 3rd star in Cygnus.

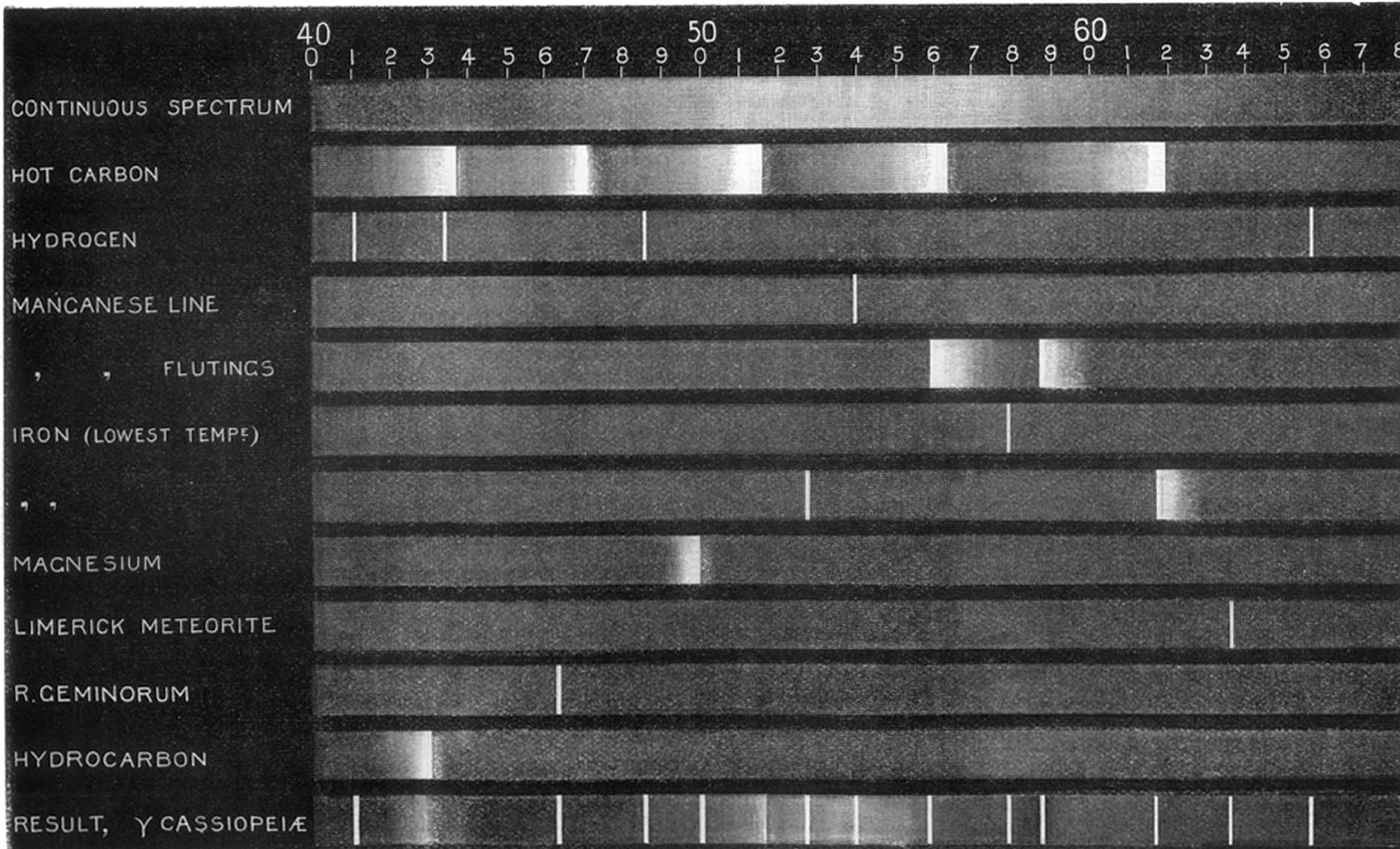

FIG. 11 (γ Cassiopeiæ).—Map shewing the probable origin of the spectrum of γ Cassiopeiæ.

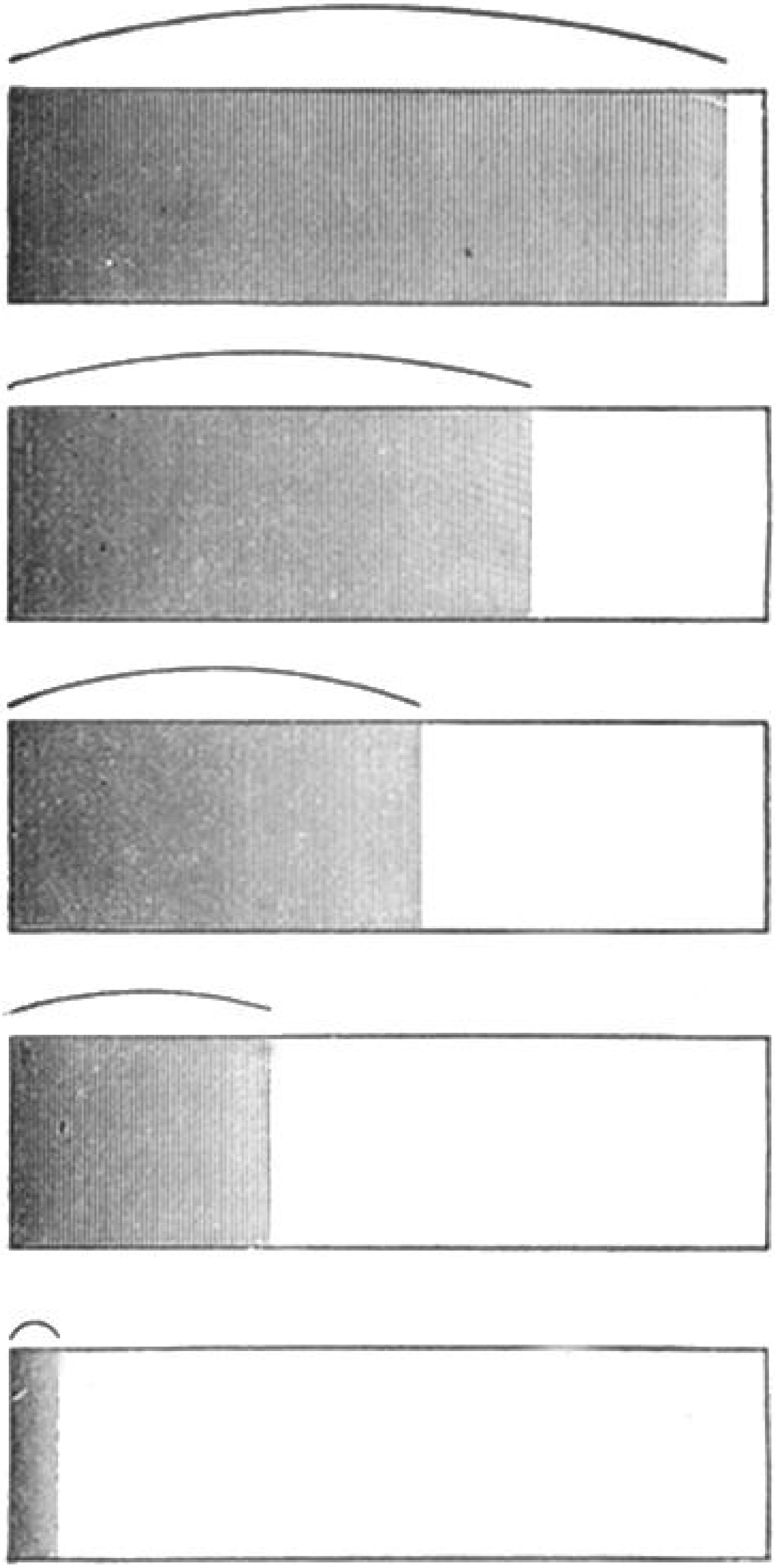

FIG. 12.—Diagram showing how an absorption fluting varies in width according to the quantity of absorbing substance present.

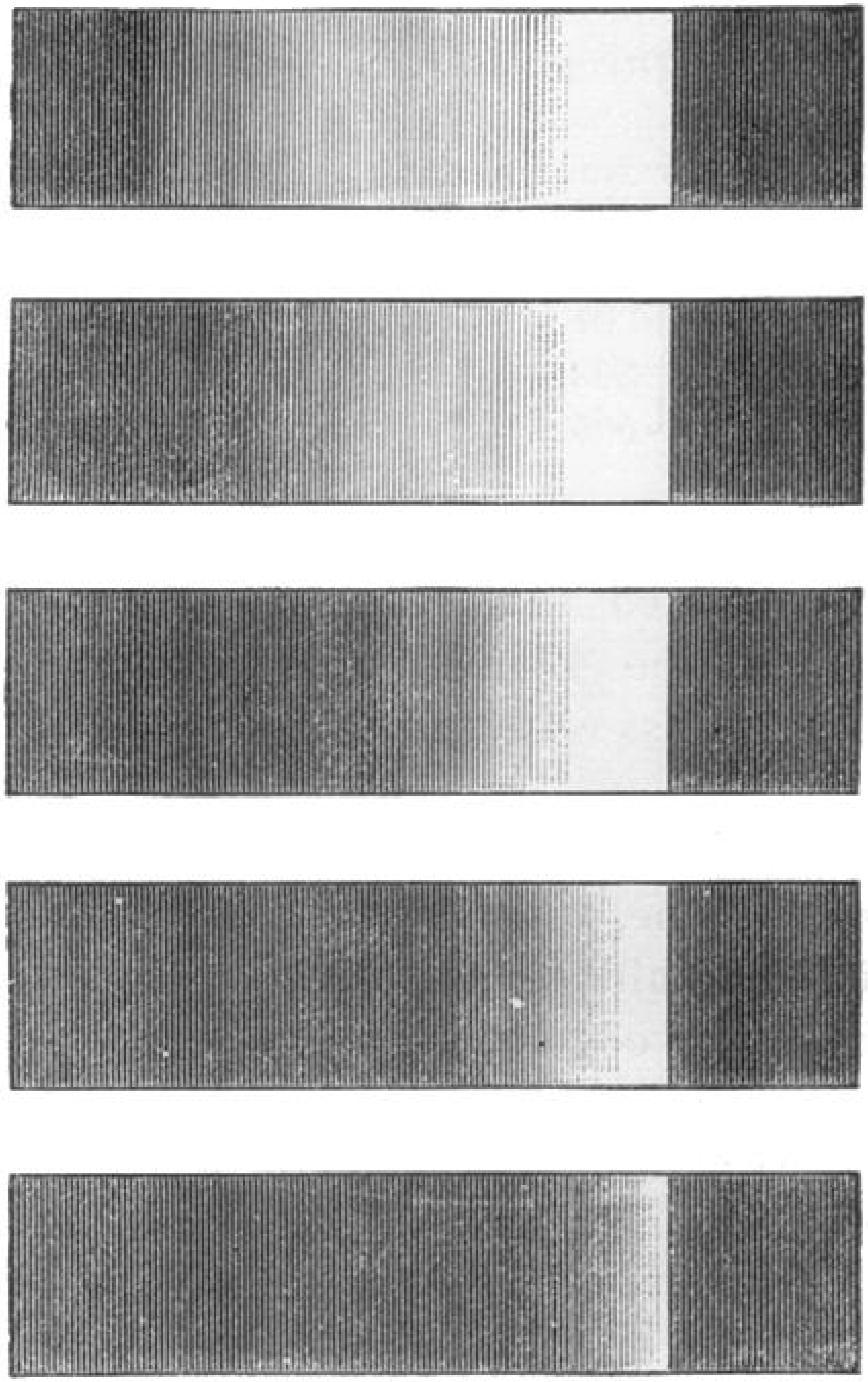

FIG. 13.—Diagram showing the variation in width of a bright fluting and the consequent variation in width of the contrast band at the fainter edge.

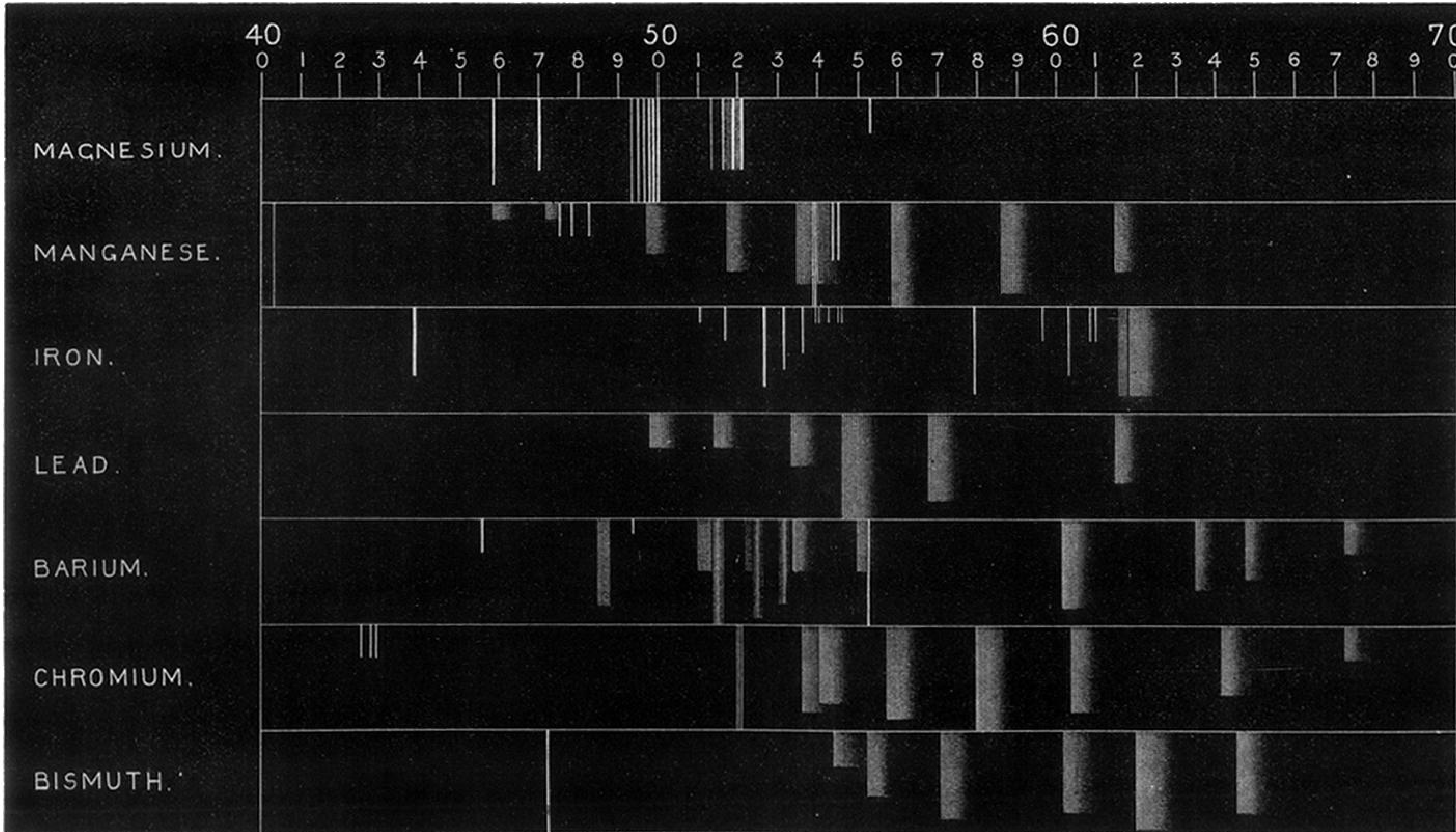

FIG. 14.—Map showing the lines, bands, and flutings seen in the spectra of the elements which are indicated in bodies of Group II.

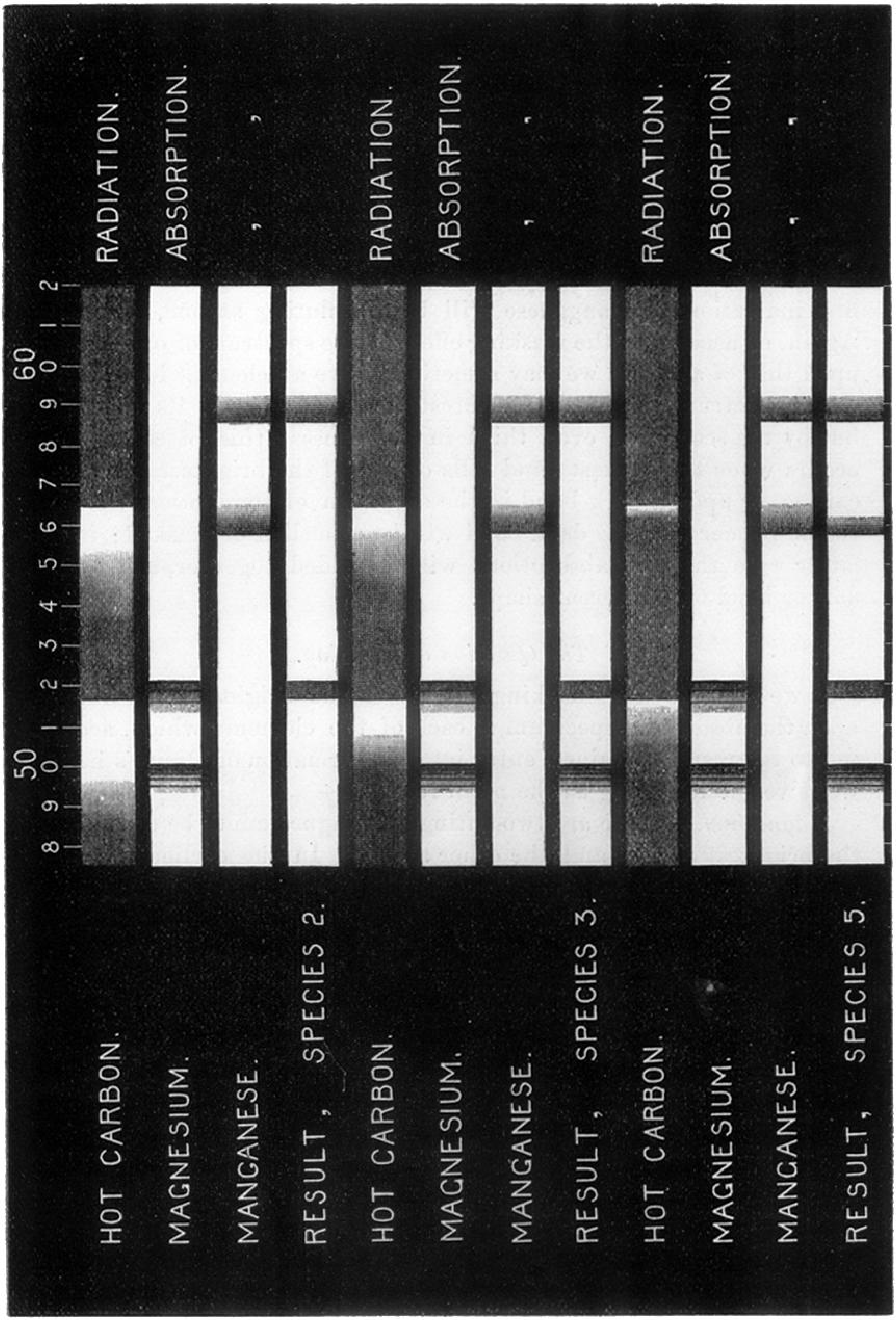

Fig. 15.—Diagram showing the effects of variations in width of the flutings of carbon upon the integrated spectra of carbon radiation and magnesium and manganese absorption, as they appear in different species of bodies of Group II.

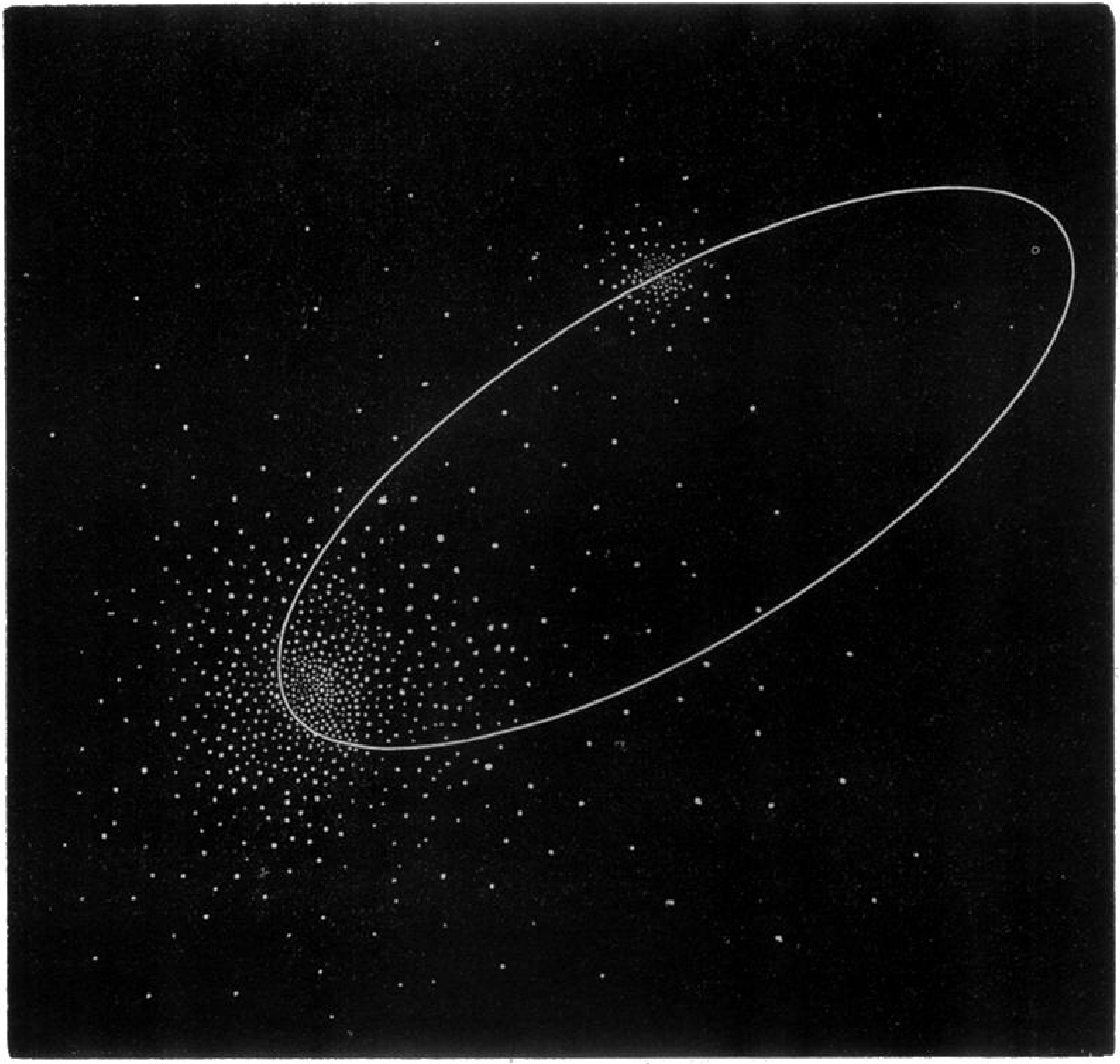

FIG. 17.—Explanation of the variability of bodies of Group II. (1.) Maximum variation. The ellipse represents the orbit of the smaller swarm, which revolves round the larger. The orbit of the revolving swarm is very elliptical, so that at periastron the number of collisions is enormously increased.

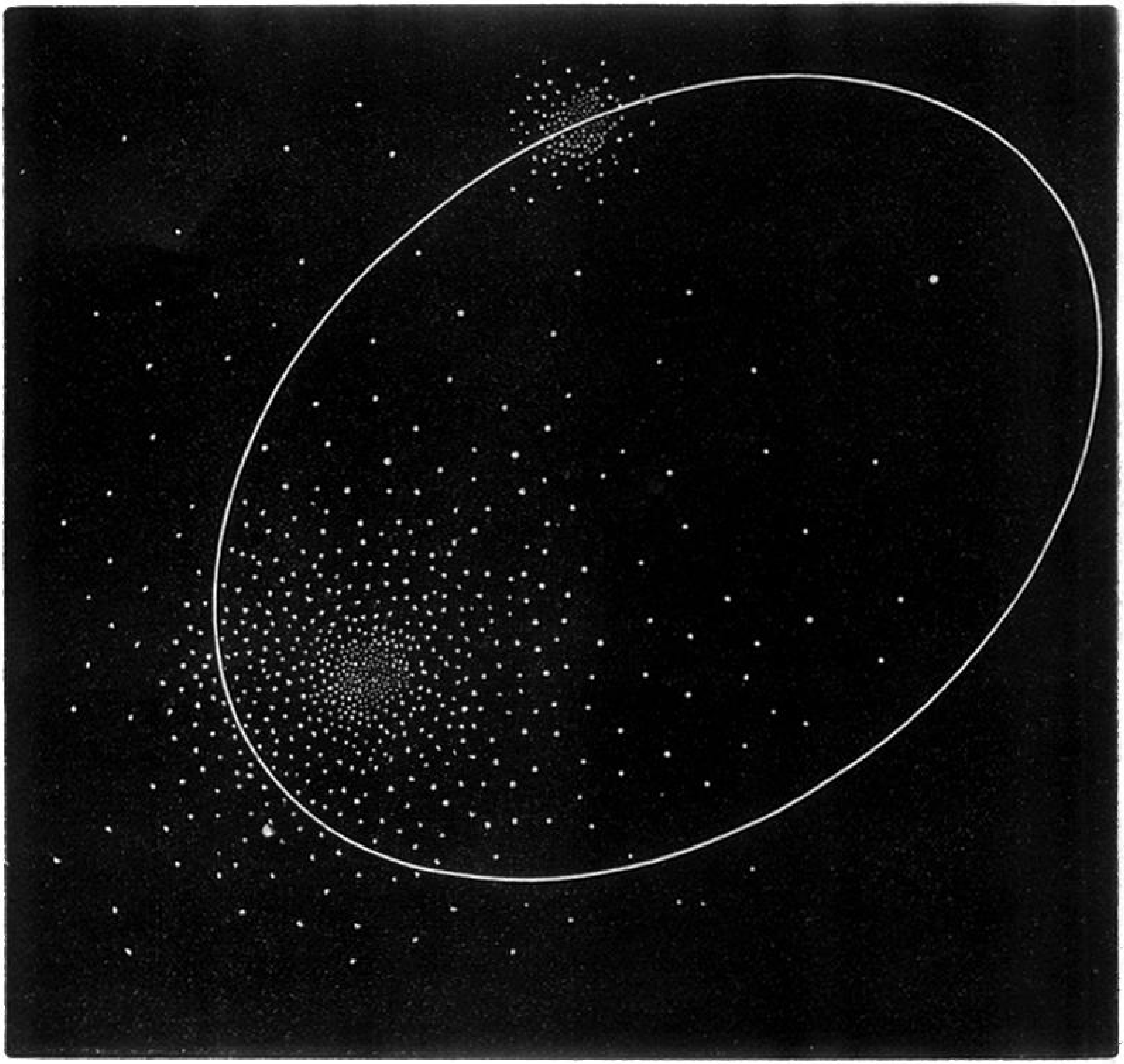

FIG. 18.—Explanation of the variability of bodies of Group II. (2.) Medium variation. In this case, there will be a greater number of collisions at periastron than at other parts of the orbit. The variation in the light, however, will not be very great under the conditions represented, as the revolving swarm never gets very near the middle of the central one.

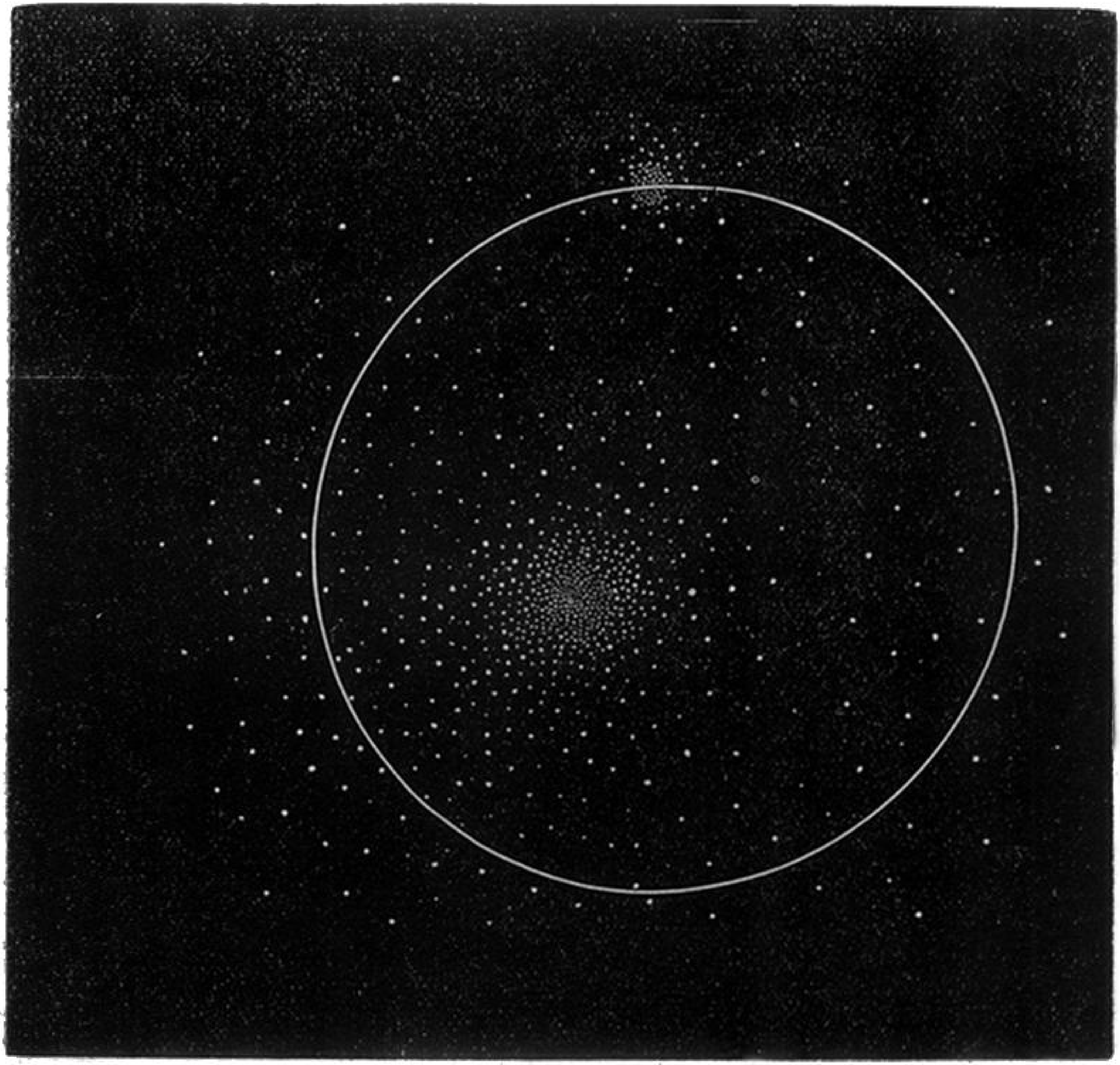

FIG. 19.—Explanation of the variability of bodies of Group II. (3.) Minimum variation. Under the conditions shown, the smaller swarm will never be entirely out of the larger one, and at periastron the number of collisions will not be very greatly increased. Consequently, the variation in the amount of light given out will be small.